



Expected Accuracy of Decadal Trends from ALL-Sky IR Radiance Spectra – A 100-yr Climate Model Simulation

W. L. Smith Sr., E. Weisz, R. Knuteson, H.E. Revercomb, X. Liu, C. Zhou
(With contributions from Daniel Feldman and Bill Collins)

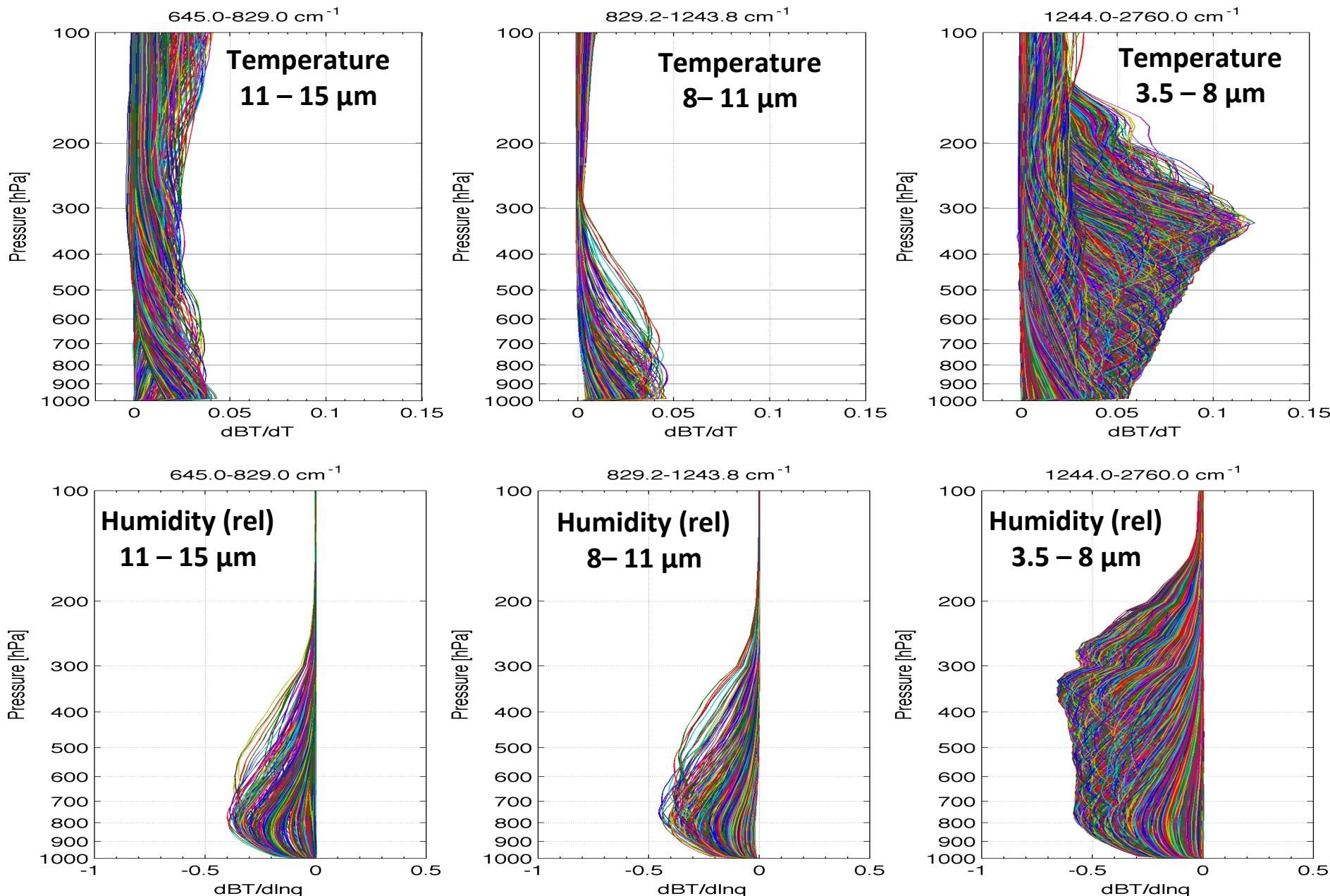
University of Wisconsin Space Science and Engineering Center - Madison



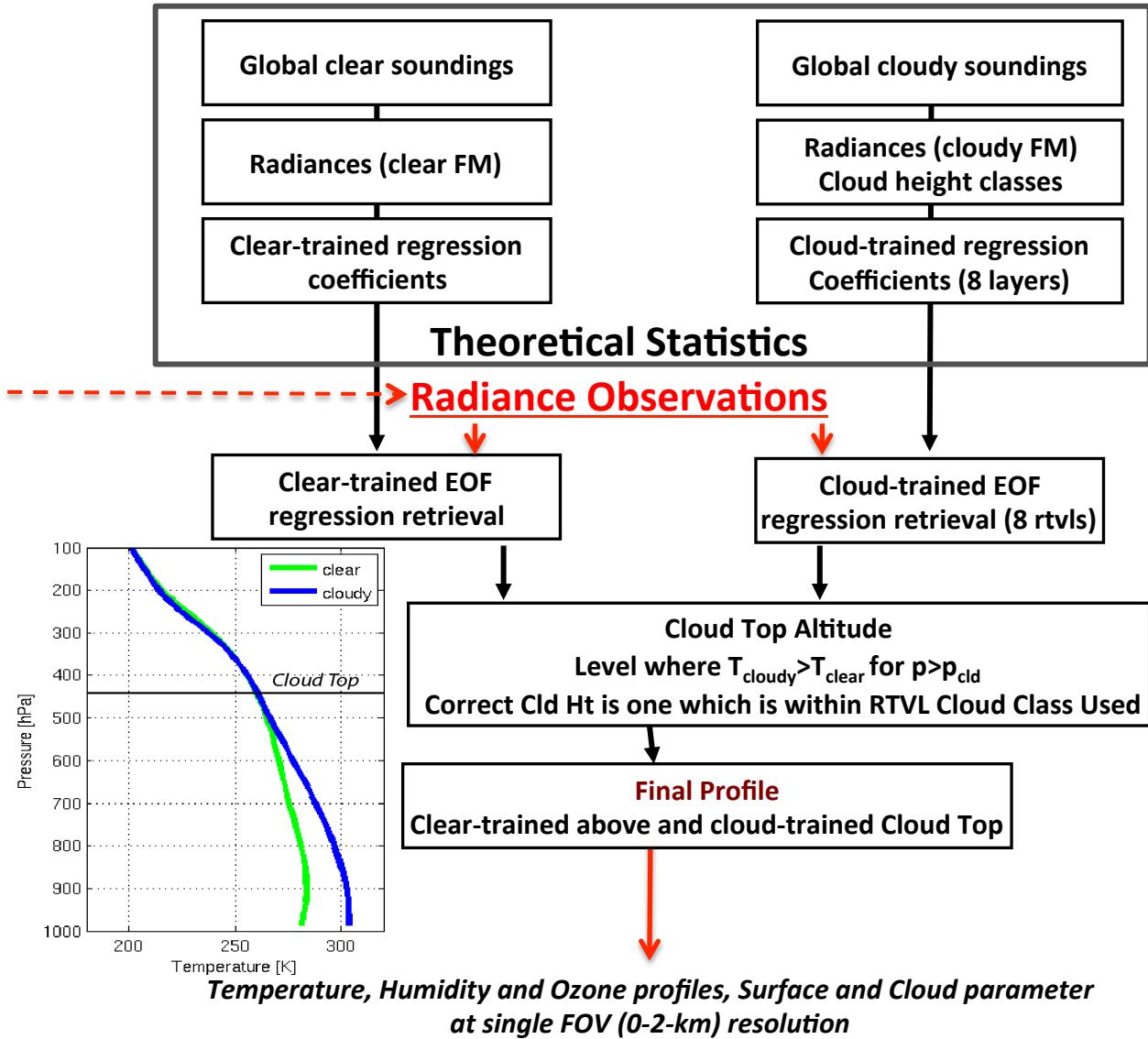
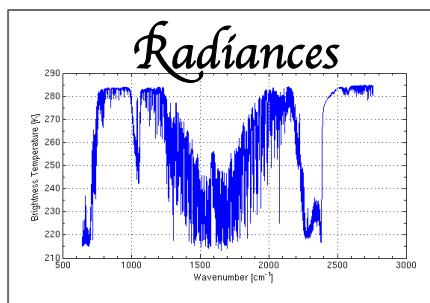
CLARREO Science Definition Team Meeting
National Institute for Aerospace (NIA)
November 29 – December 1, 2016



IASI Temperature and Humidity Weighting Functions



All-Sky “Dual-Regression” Retrieval Algorithm*



- Smith, W. L., E. Weisz, S. Kirev, D. K. Zhou, Z. Li, and E. E. Borbas (2012), Dual-Regression Retrieval Algorithm for Real-Time Processing of Satellite Ultraspectral Radiances. *J. Appl. Meteor. Clim.*, 51, Issue 8, 1455-1476.
- Weisz, E., W. L. Smith, N. Smith (2013), Advances in simultaneous atmospheric profile and cloud parameter regression based retrieval from high-spectral resolution radiance measurements, *J. of Geophys. Res.-Atmospheres*, 118, 6433-6443.

How Well Can We Retrieve Decadal Trends ?

- **Use CCSM Climate Model 100-yr CO₂ Doubling OSSE***
- **Simulate CLARREO Radiance Spectra from Model Output**
 - Monthly Mean Atmospheric Profiles and Cloud and Surface Parameters for ~1.5 Deg. Grid from CCSM
 - PCRTM Produced Radiance Spectra
 - NASA 0.5 deg. surface emissivity database developed by Daniel Zhou (NASA/LaRC)
 - PCRTM Cloud phase, optical depth, and particle size specified from CCSM cloud parameters (cloud liquid water mixing ratio, cloud ice mixing ratio, an assumed cloud thickness)
- **Perform DR Retrievals From Monthly Average CCSM Grid Point Radiances**
 - Clear Sky ** (Results shown at May 2016 SDT meeting)
 - All Sky (Results presented here)
- **DR Retrievals**
 - Dependent sample training statistics (2000–2100 Climate Statistics)
 - Uses subset of CCSM OSSE simulated radiances and associated surface and atmospheric variables
 - 36 randomly selected grid points per month = 43,200 samples)
 - 2000-2100 CO₂ variability (370 - 820 ppm)
 - 0.1 K random forward model error assumed
 - Independent sample training statistics (No Climate Change Statistics)
 - Uses UW Direct Broadcast DR (SeeBor training data base)
 - CO₂ doubling random variability (370 - 800 ppm)
 - 0.1 K random forward model error assumed

* Data provided by D. R. Feldman, CLARREO SDT

** Cong et. al., 2016: “On the use of satellite-based hyperspectral sounder to study climate trends”, Journal of Applied Meteorology and Climatology (submitted)

OSSE Cloudy Radiances and All-sky Retrievals

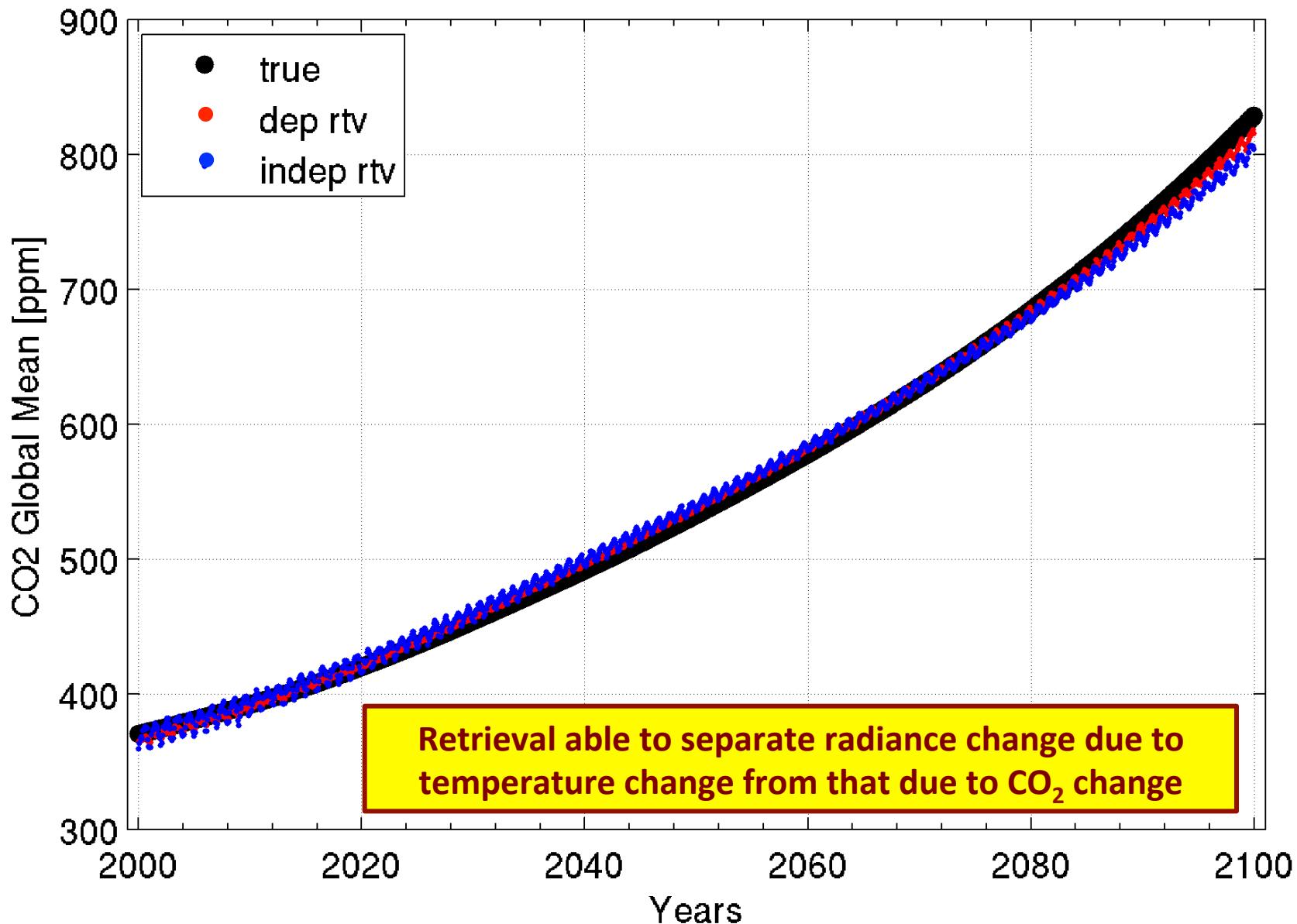
1. From OSSE input file: CLDICE, CLDLIQ and CLOUD (all nprofs x nlevs); CLDTOT (nprofs x 1)
2. For pressure levels below 90 hPa and if CLOUD (=cloud fraction) is larger than 0.01 then determine cloud optical thickness, effective radius and phase from CLDICE, CLDLIQ and CLOUD. Set CTOP to respective pressure level. 18 cloud top pressure levels in total (see table).

1	3.54	
2	7.39	
3	13.97	
4	23.94	
5	37.23	
6	53.11	
7	70.06	
8	85.44	
9	100.51	1
10	118.25	2
11	139.12	3
12	163.66	4
13	192.54	5
14	226.51	6
15	266.48	7
16	313.50	8
17	368.82	9
18	433.90	10
19	510.46	11
20	600.52	12
21	696.80	13
22	787.70	14
23	867.16	15
24	929.65	16
25	970.55	17
26	992.56	18

3. Run PCRTM FM on 18 cloudy files and one clear file → 19 radiance files per grid point per month.
4. Perform DR retrieval on all 19 radiance files → 19 retrieval files per grid point per month
[cloud height is assumed to be unknown (i.e., retrieved)]
5. For each level combine 19 retrieved profiles according to
$$T = (1 - \sum(cf_i)) * T_0 + \sum(cf_i * T_i)$$
 T_0 ...clear retrieval,
 T_i ... cloudy retrieval, cf_i ... cloud fraction, with $i=1,2,\dots,18$.
 cf_i are scaled cloud fractions, i.e., $cf_i = cf_{orig,i} * (CLDTOT / \sum(cf_{orig,i}))$
(linear combinations of single cloud level retrievals assumes high spatial resolution instrument. Multi-level cloud result shown later)
6. Calculate grid point decadal trends and global mean decadal trends

Note: 32,768 profiles/grid point/mo. = ~ 40 M Clear sky spectra &
~ 1 B cloudy radiance spectra calculations/OSSE

CO₂ Predictability

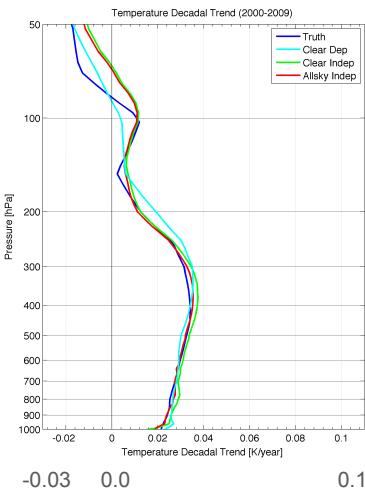


Global Mean

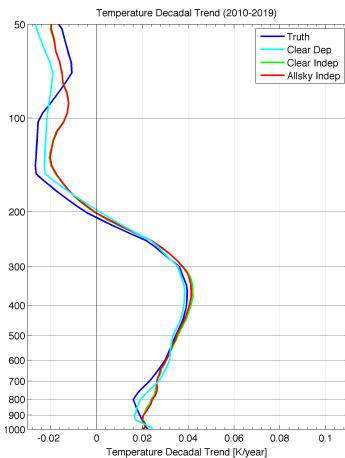
Decadal Trend (K/yr)

— Truth
— Clear Dep
— Clear Indep
— Allsky Indep

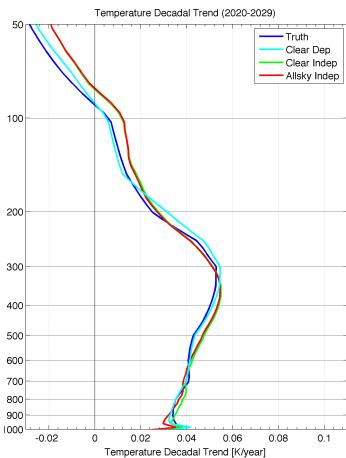
2000-2009



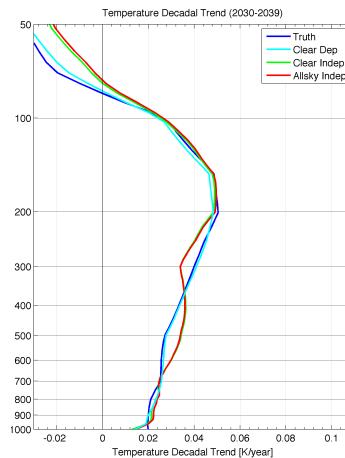
2010-2019



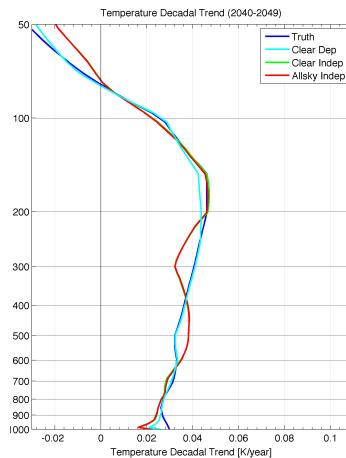
2020-2029



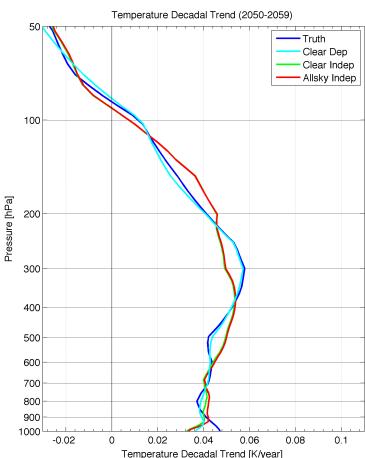
2030-2039



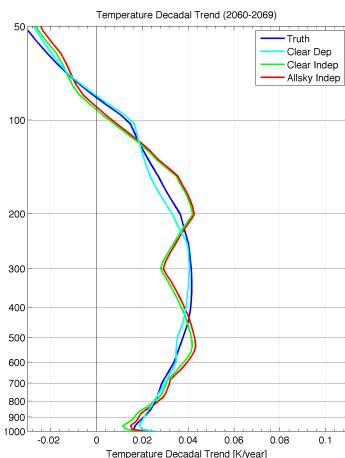
2040-2049



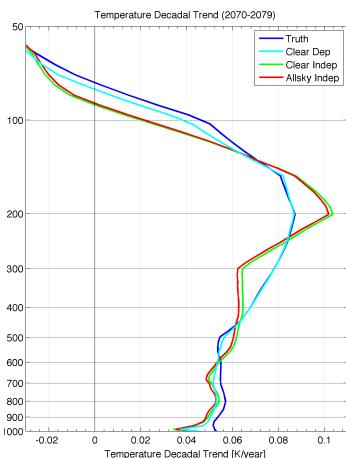
2050-2059



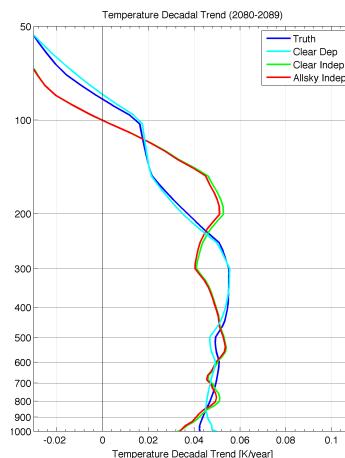
2060-2069



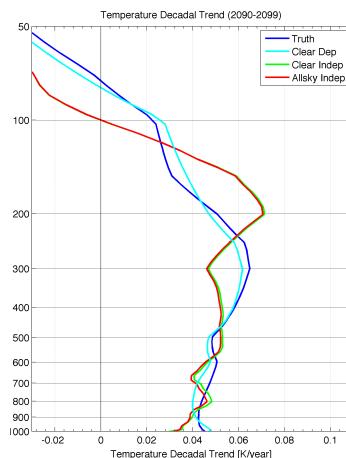
2070-2079



2080-2089

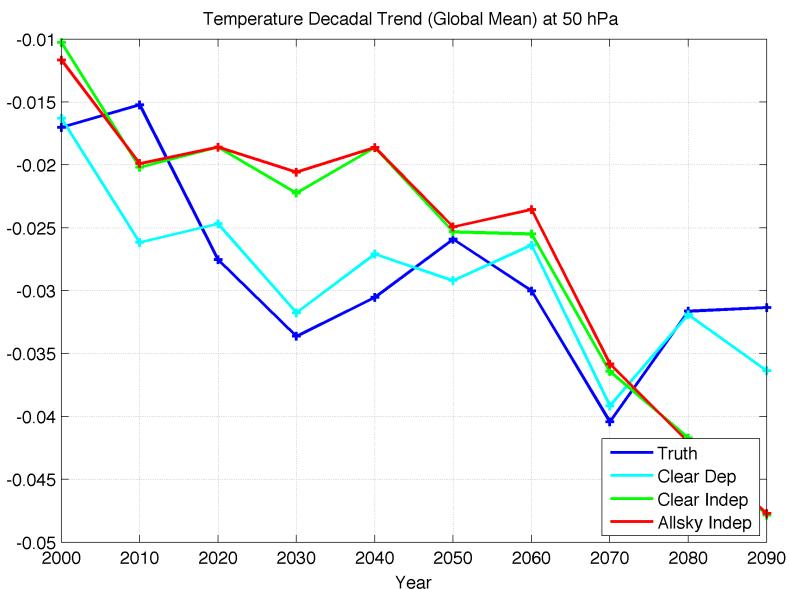


2090-2099

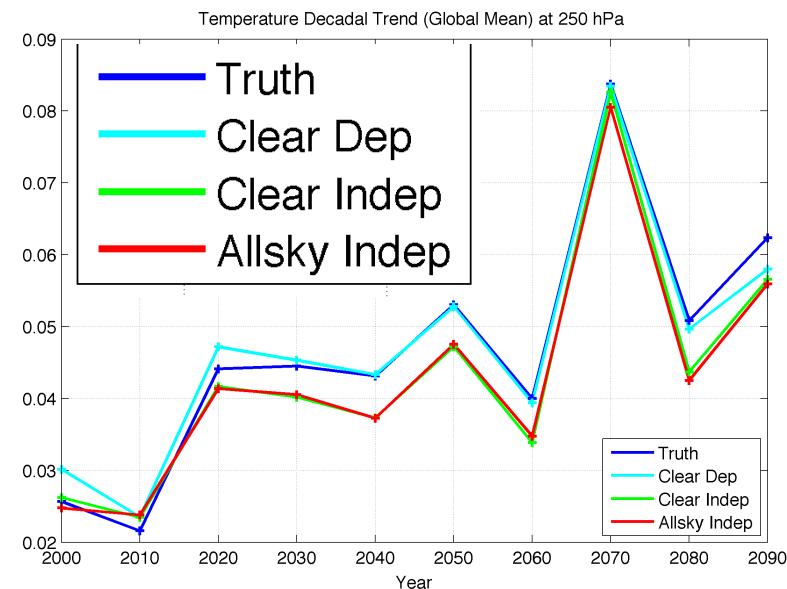


Global Mean Decadal Temperature Trends (K/yr)

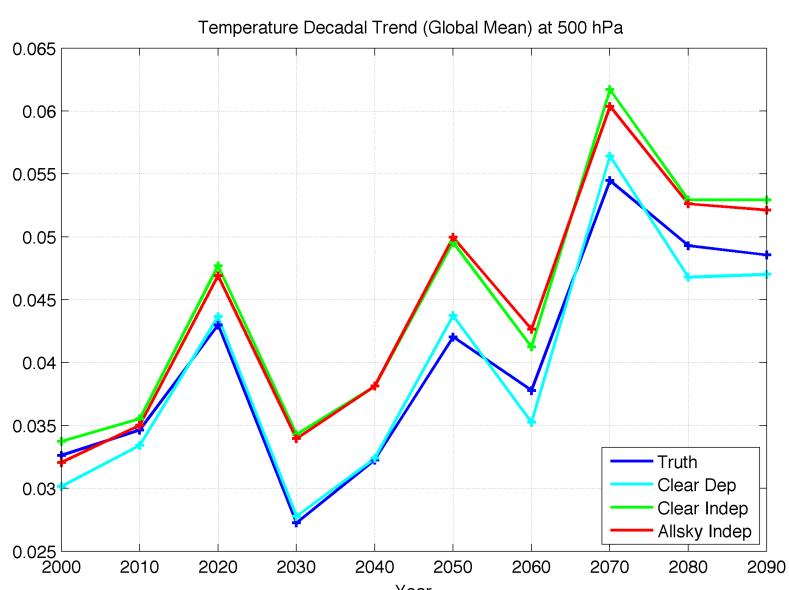
50 hPa



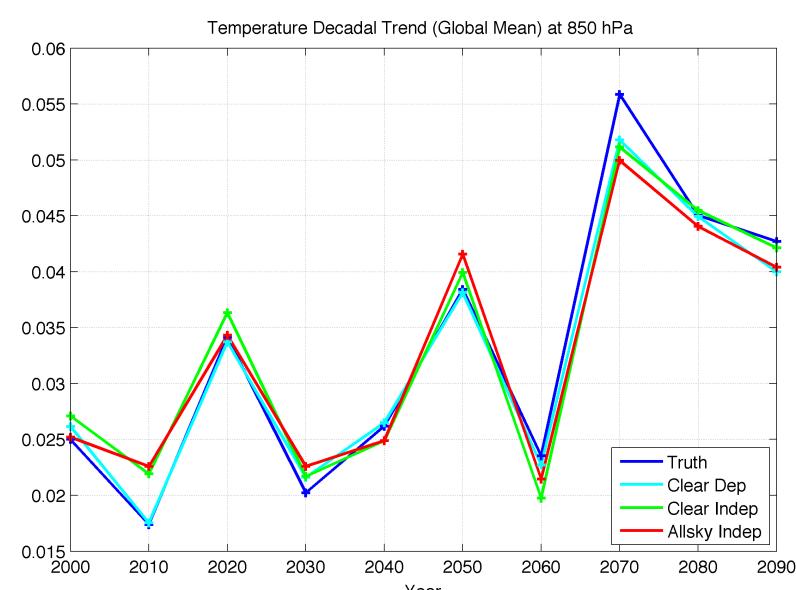
250 hPa



500 hPa



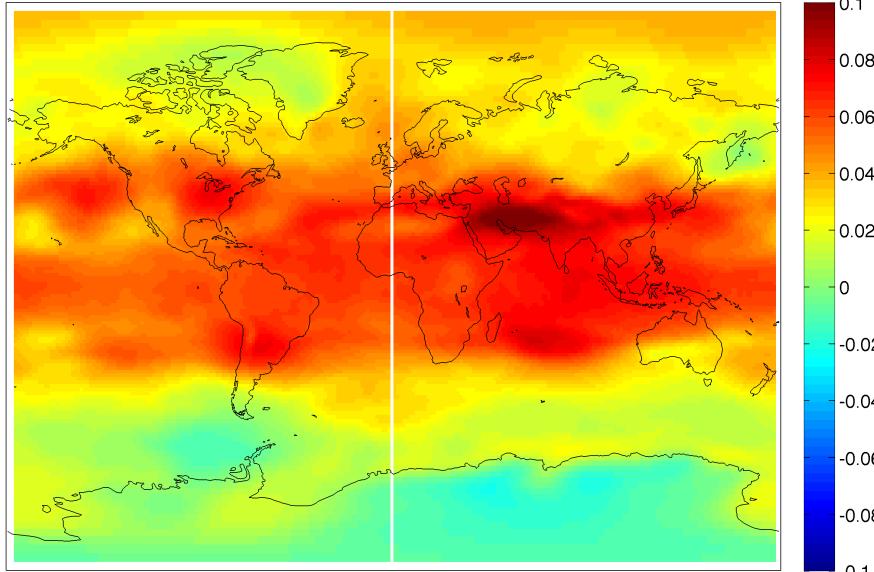
850 hPa



250 hPa 100-yr Mean Decadal Trend (K/yr)

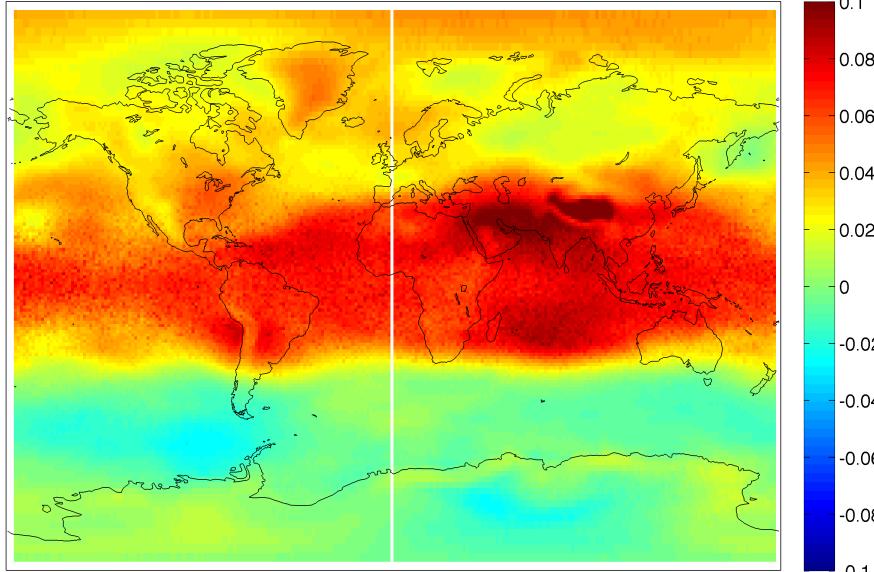
Truth

True Temperature 100-yr Mean Decadal Tend [K/yr] at 250 hPa



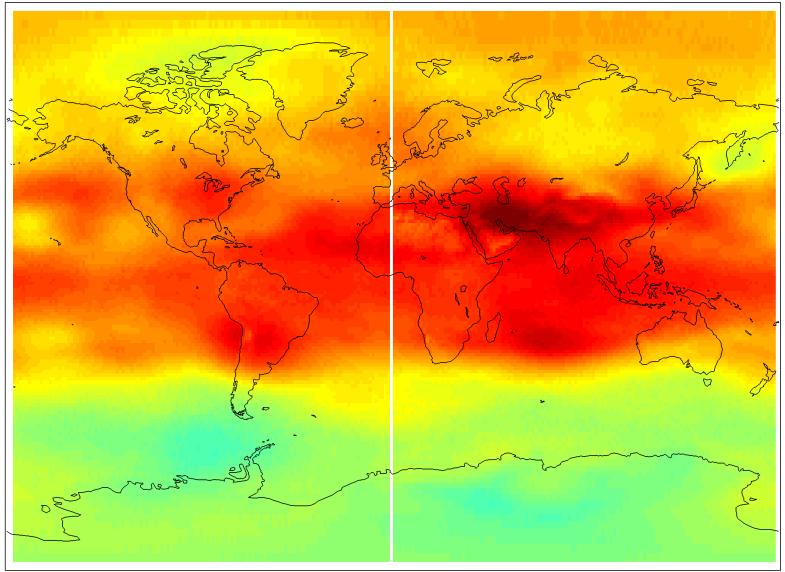
Clear Indep

Clear Temperature 100-yr Mean Decadal Tend [K/yr] at 250 hPa



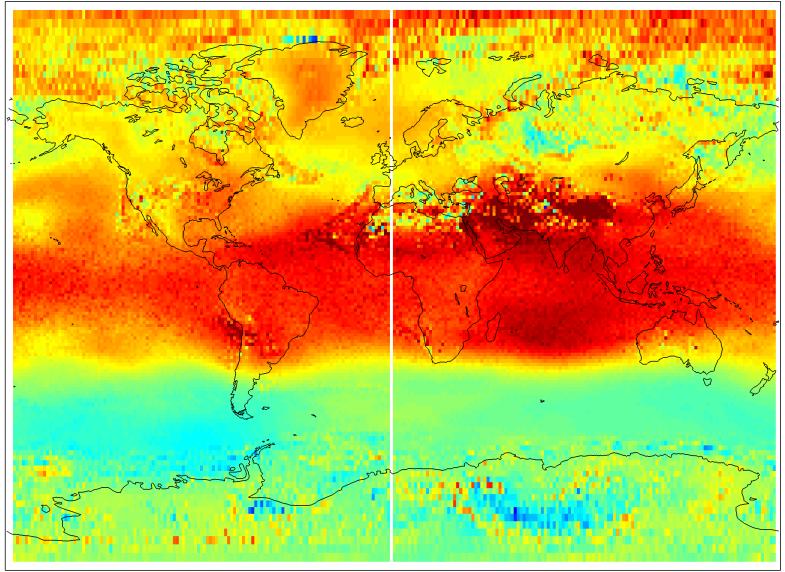
Clear Dep

Clear Dep Temperature 100-yr Mean Decadal Tend [K/yr] at 250 hPa



Allsky

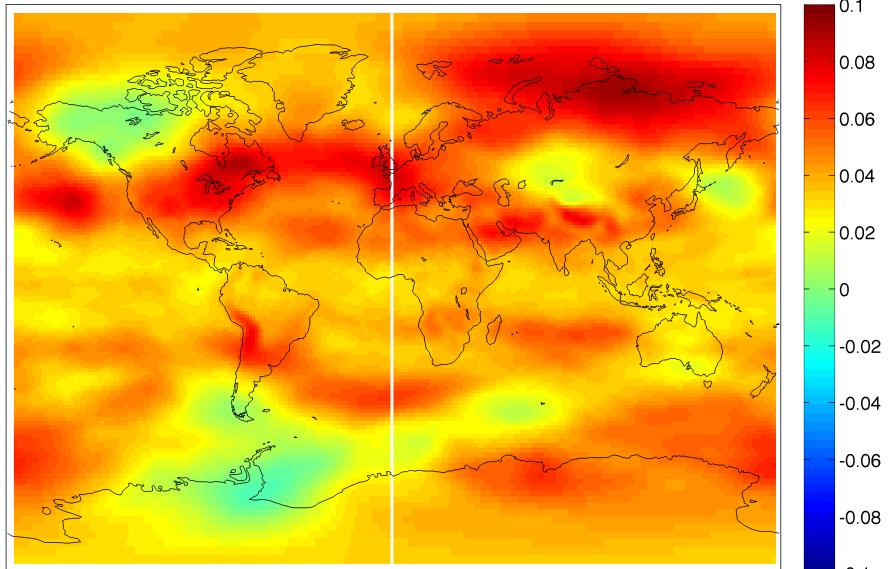
Allsky Temperature 100-yr Mean Decadal Tend [K/yr] at 250 hPa



500 hPa 100-yr Mean Decadal Trend (K/yr)

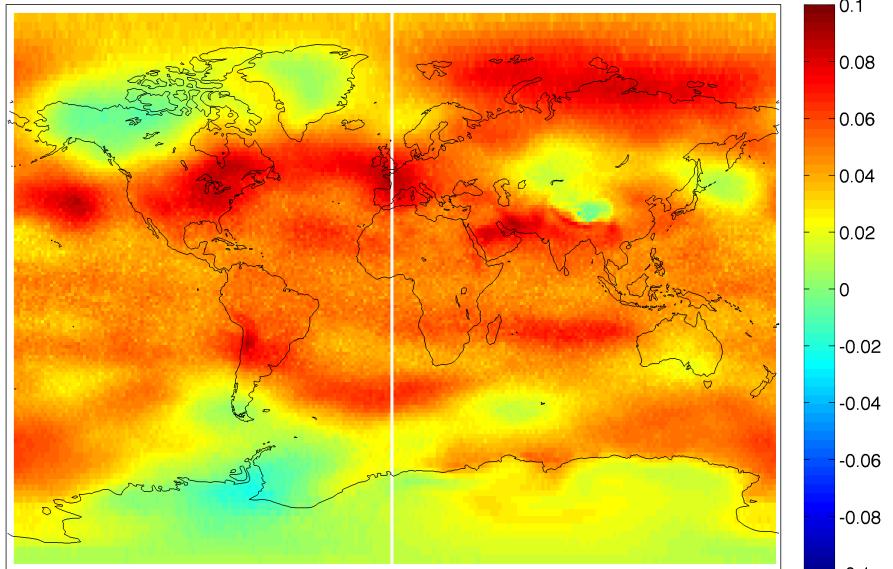
Truth

True Temperature 100-yr Mean Decadal Tend [K/yr] at 500 hPa



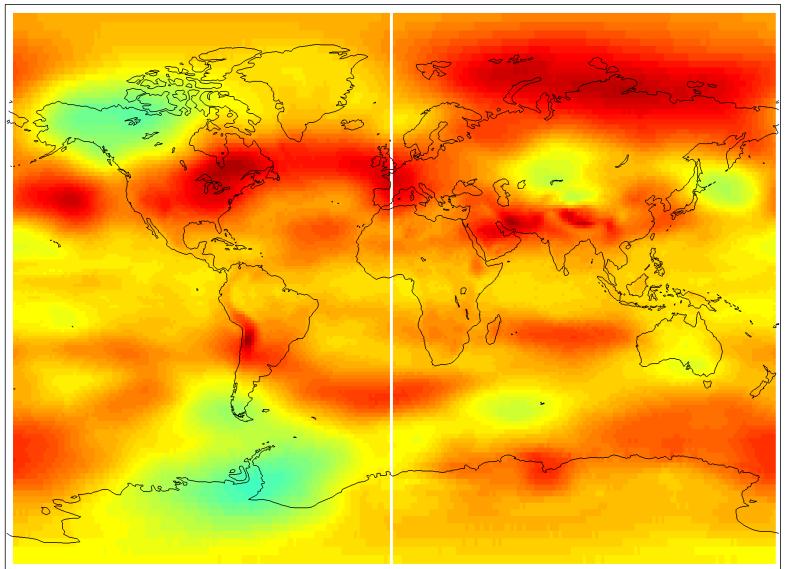
Clear Indep

Clear Temperature 100-yr Mean Decadal Tend [K/yr] at 500 hPa



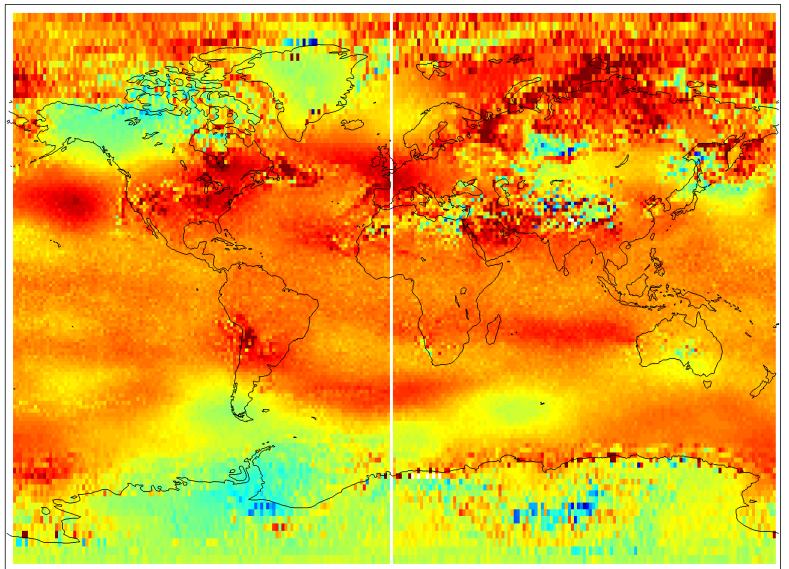
Clear Dep

Clear Dep Temperature 100-yr Mean Decadal Tend [K/yr] at 500 hPa



Allsky

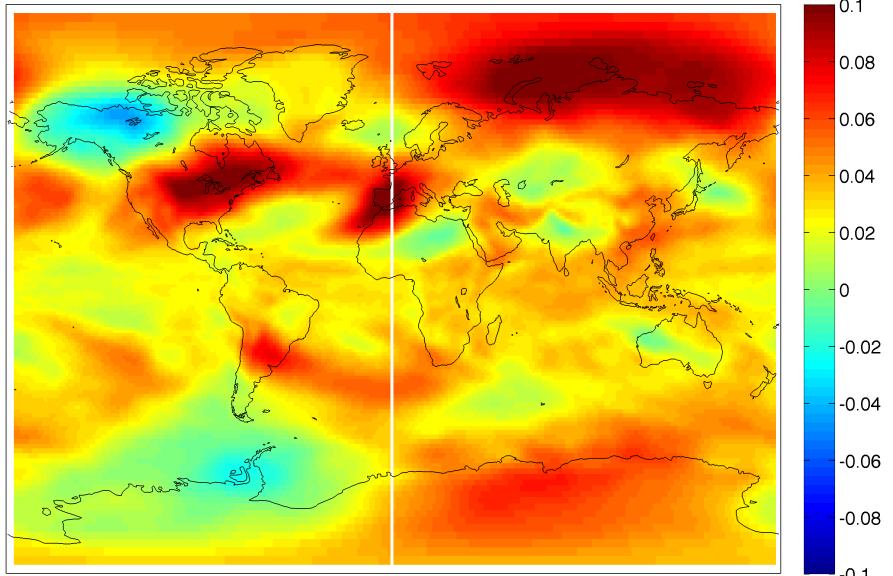
Allsky Temperature 100-yr Mean Decadal Tend [K/yr] at 500 hPa



850 hPa 100-yr Mean Decadal Trend (K/yr)

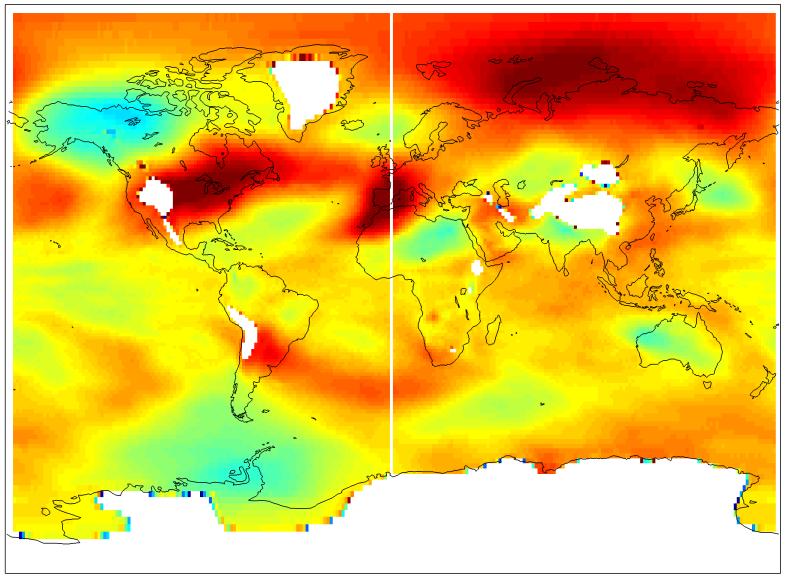
Truth

True Temperature 100-yr Mean Decadal Tend [K/yr] at 850 hPa



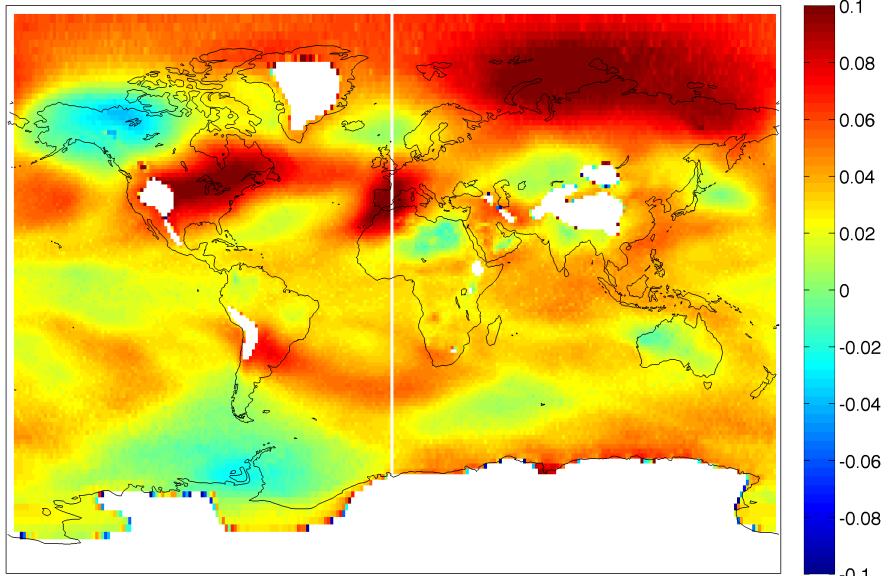
Clear Dep

Clear Dep Temperature 100-yr Mean Decadal Tend [K/yr] at 850 hPa



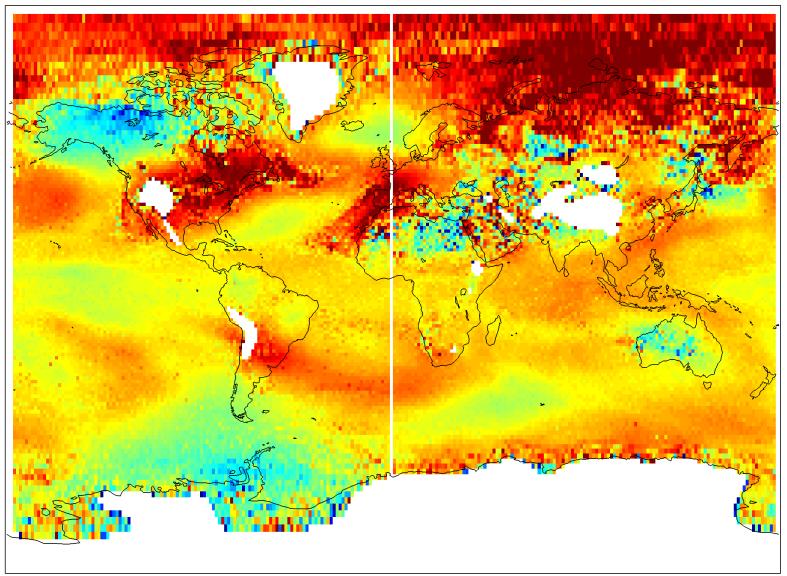
Clear Indep

Clear Temperature 100-yr Mean Decadal Tend [K/yr] at 850 hPa

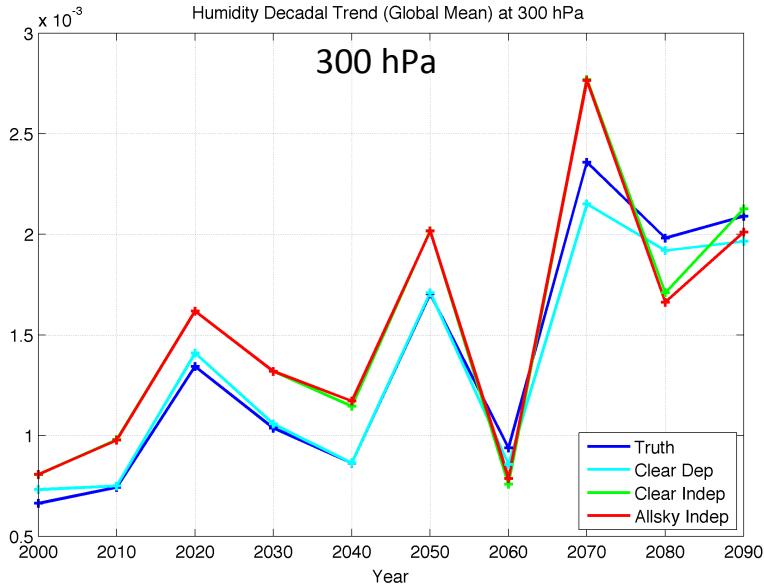


Allsky

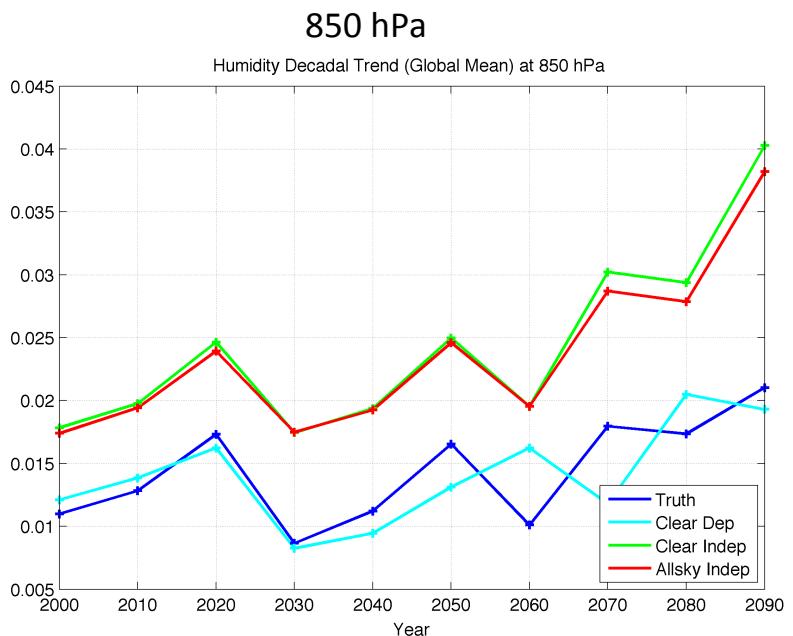
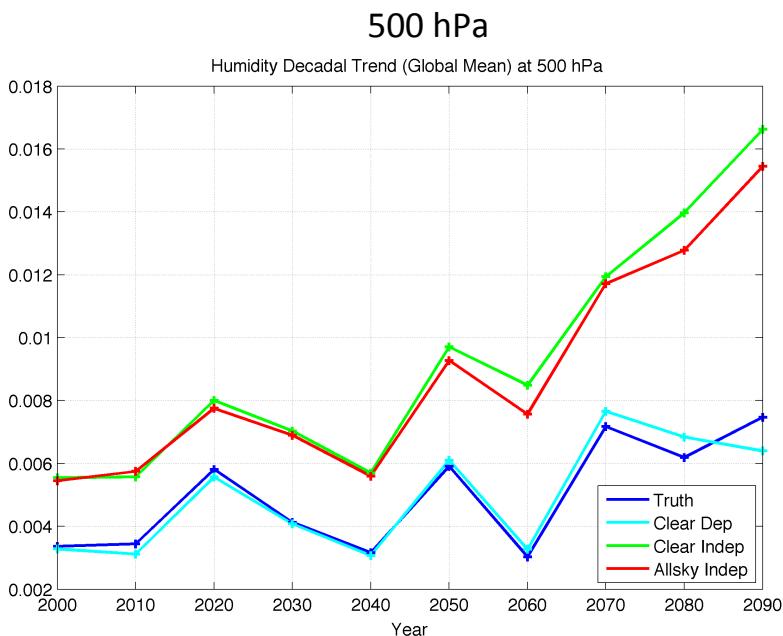
Allsky Temperature 100-yr Mean Decadal Tend [K/yr] at 850 hPa



Humidity Decadal Trend (g/kg/year)



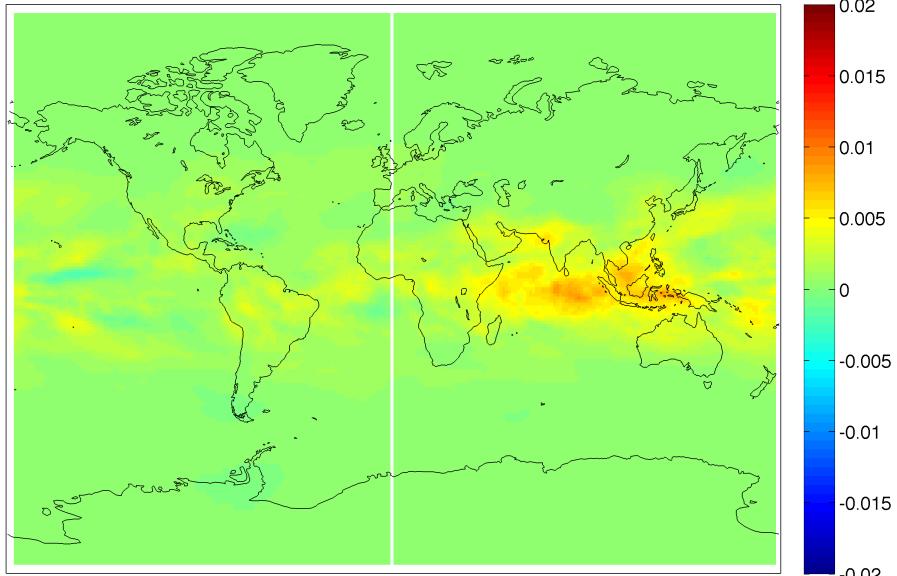
— Truth
— Clear Dep
— Clear Indep
— Allsky Indep



300 hPa 100-yr Mean Decadal Trend (g/kg/yr)

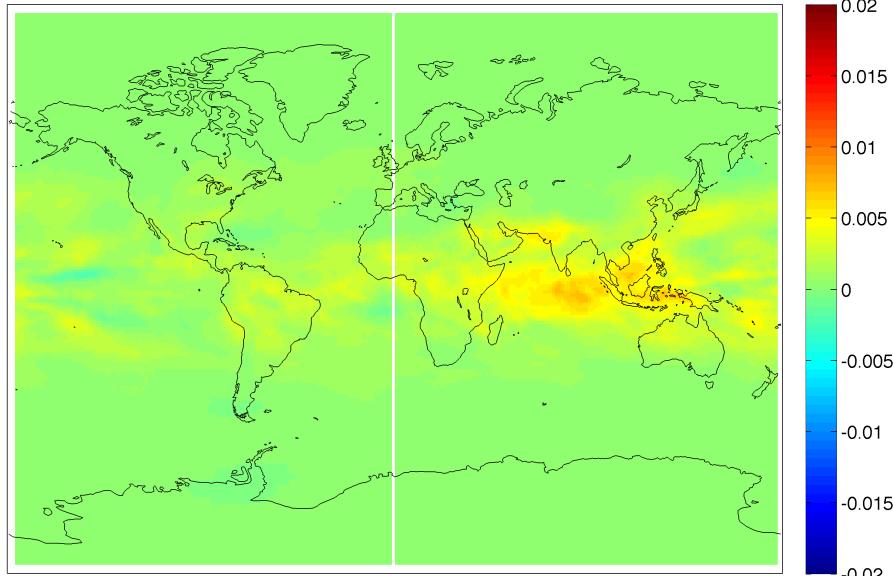
Truth

True Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 300 hPa



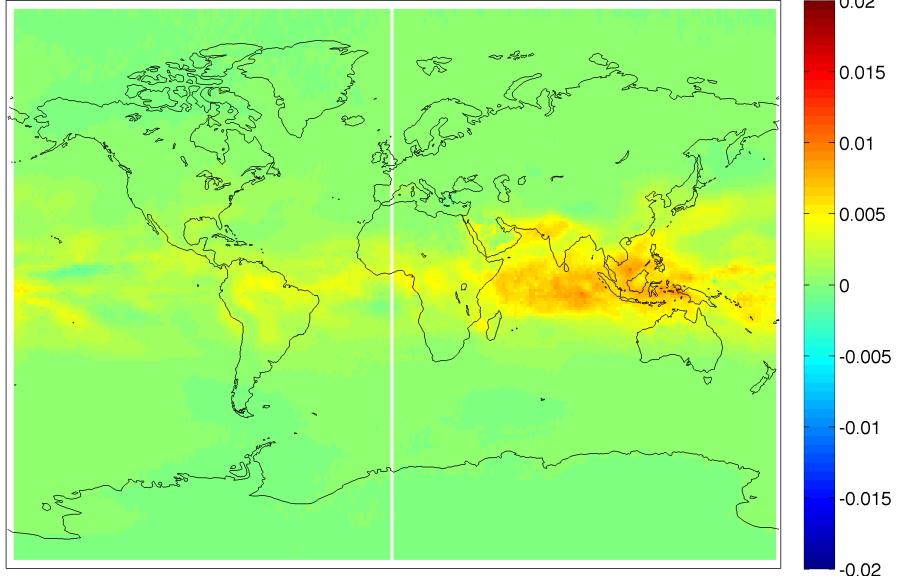
Clear Dep

Clear Dep Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 300 hPa



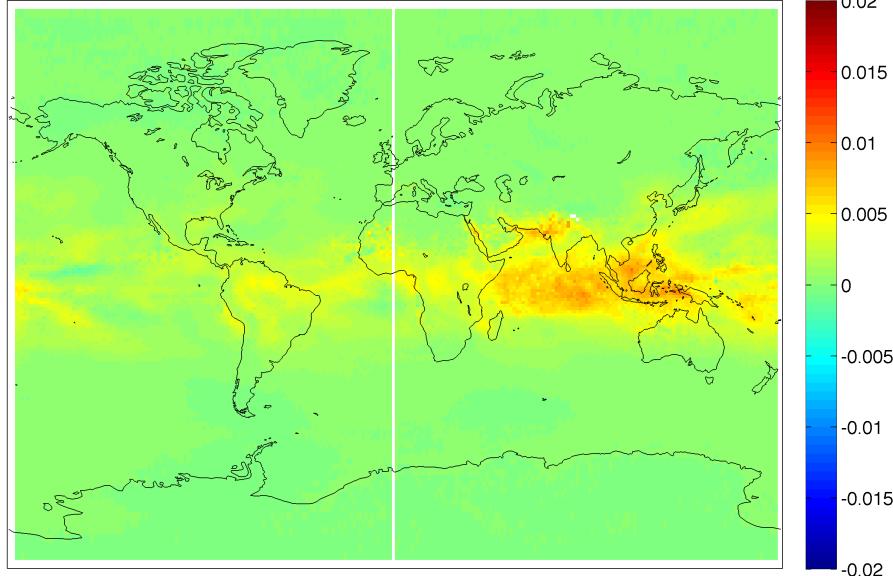
Clear Indep

Clear Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 300 hPa



Allsky

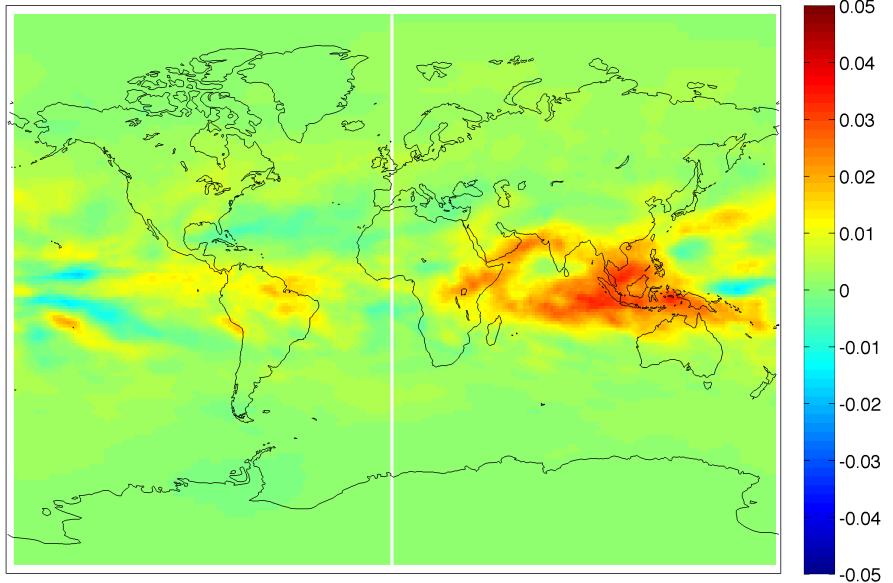
Allsky Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 300 hPa



500 hPa 100-yr Mean Decadal Trend (g/kg/yr)

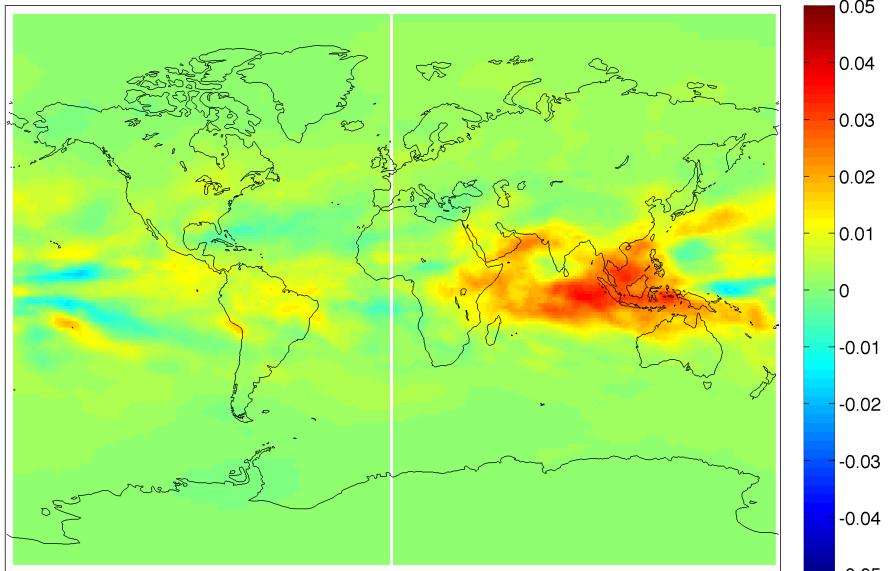
Truth

True Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 500 hPa



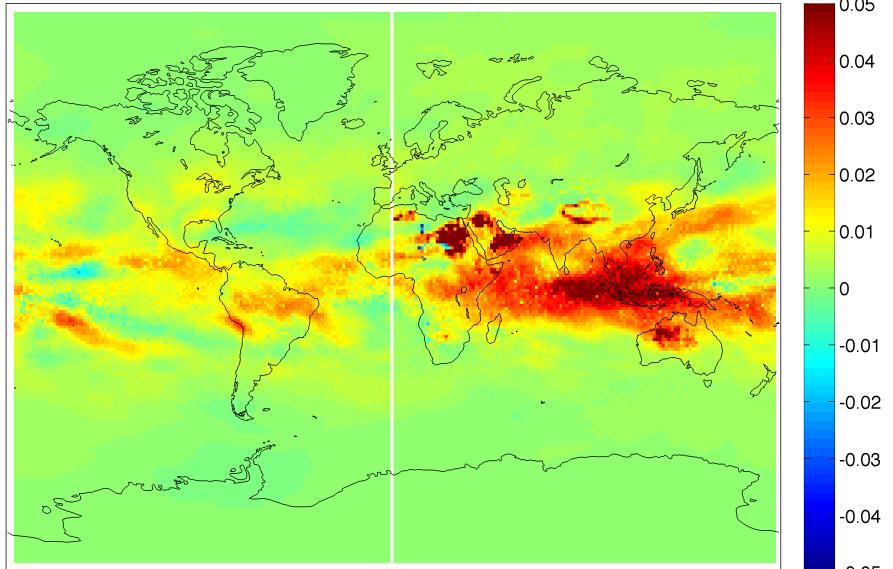
Clear Dep

Clear Dep Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 500 hPa



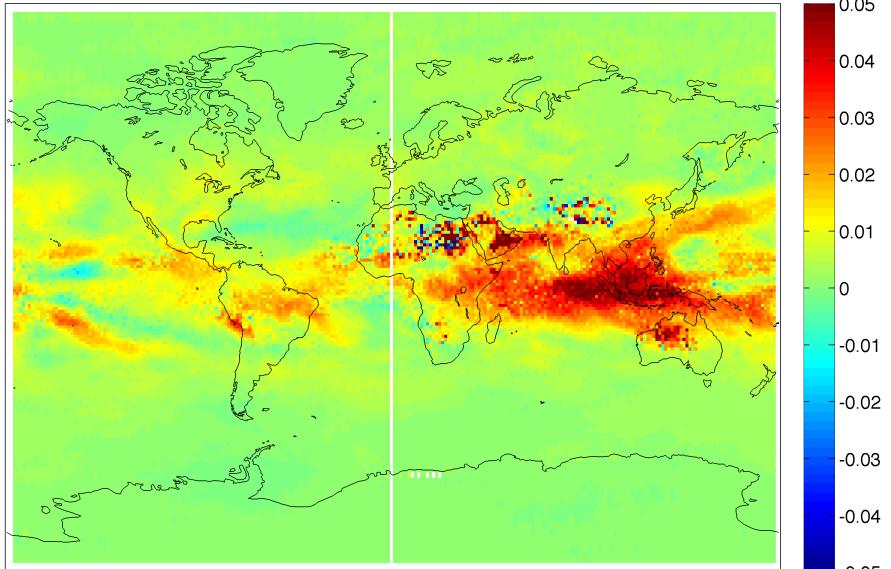
Clear Indep

Clear Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 500 hPa



Allsky

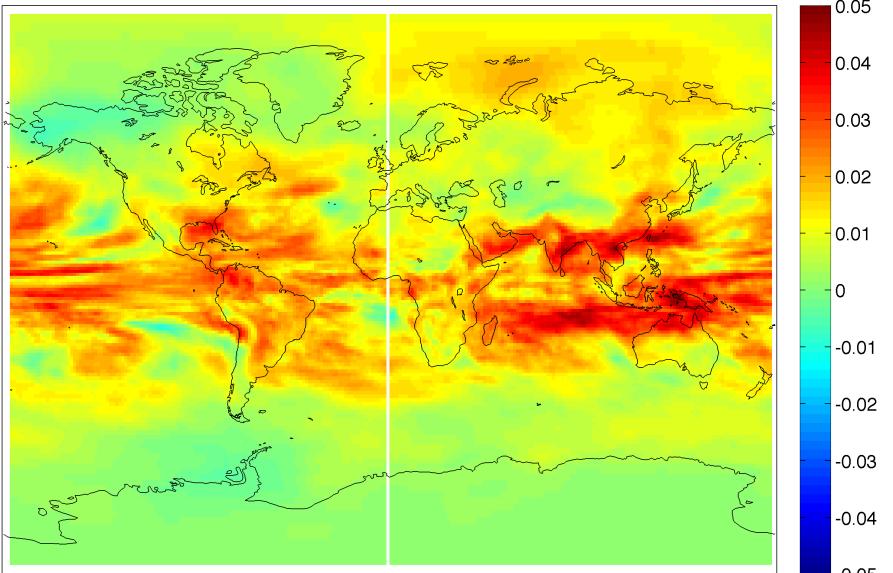
Allsky Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 500 hPa



850 hPa 100-yr Mean Decadal Trend (g/kg/yr)

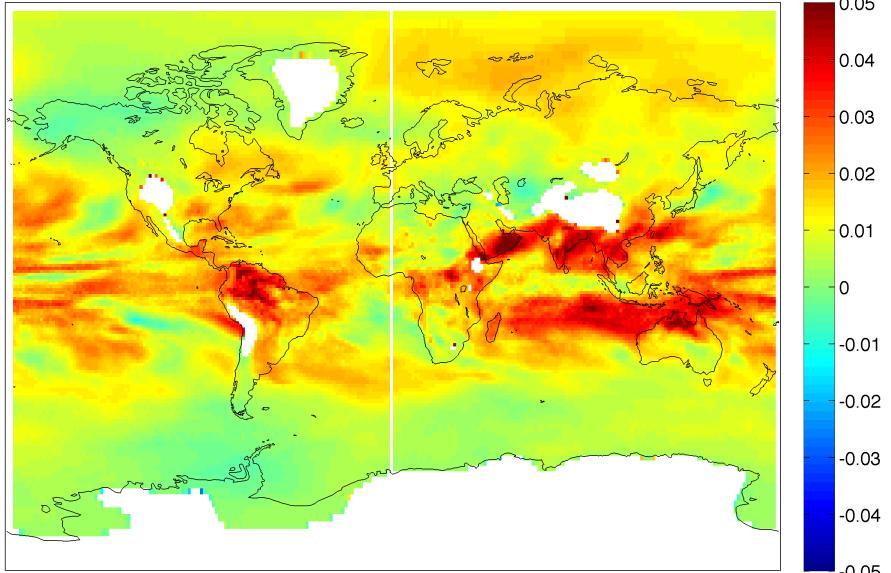
Truth

True Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 850 hPa



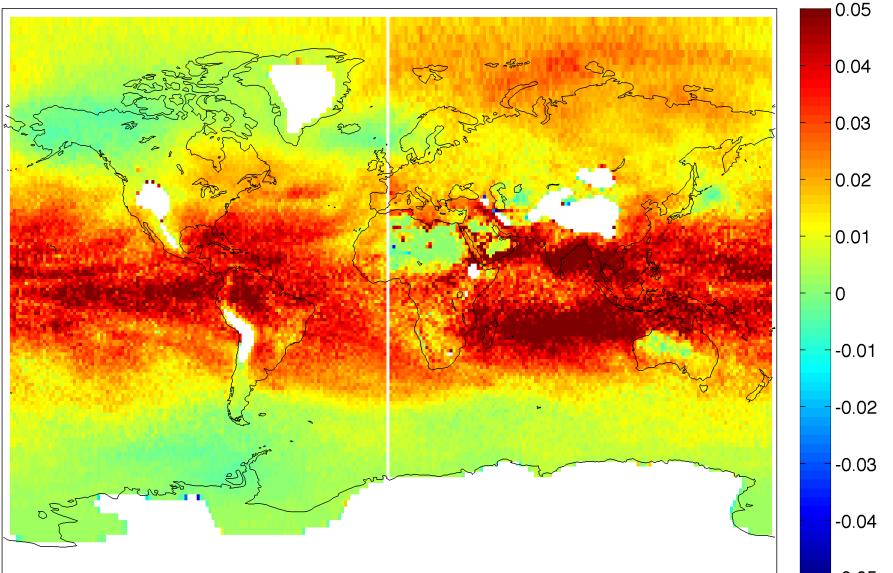
Clear Dep

Clear Dep Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 850 hPa



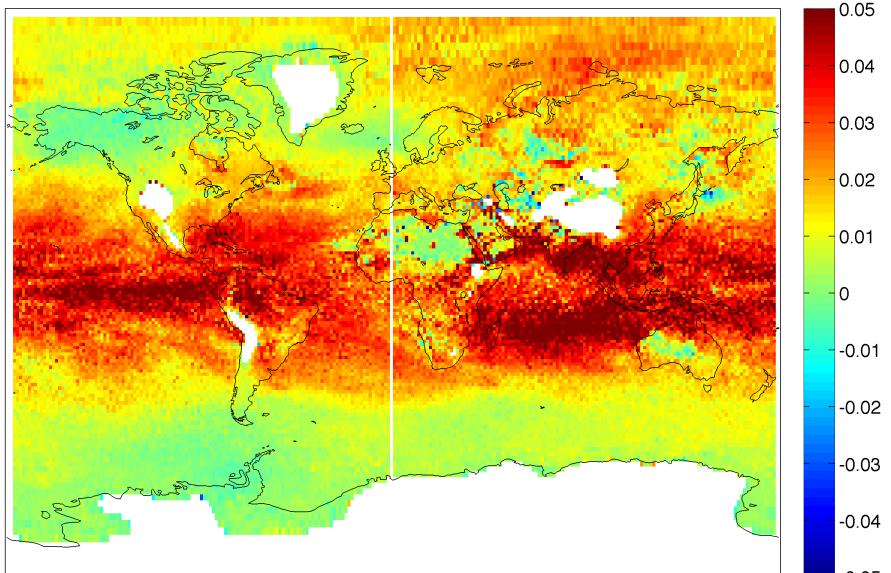
Clear Indep

Clear Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 850 hPa

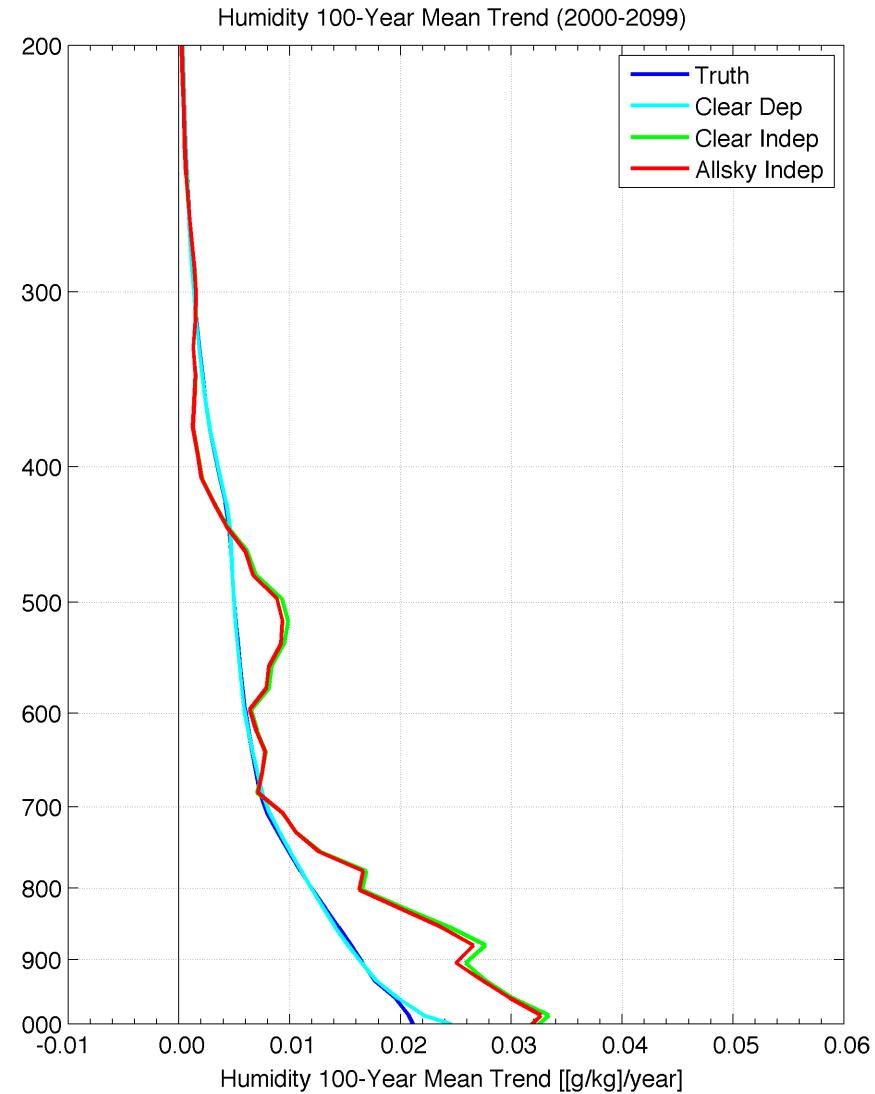
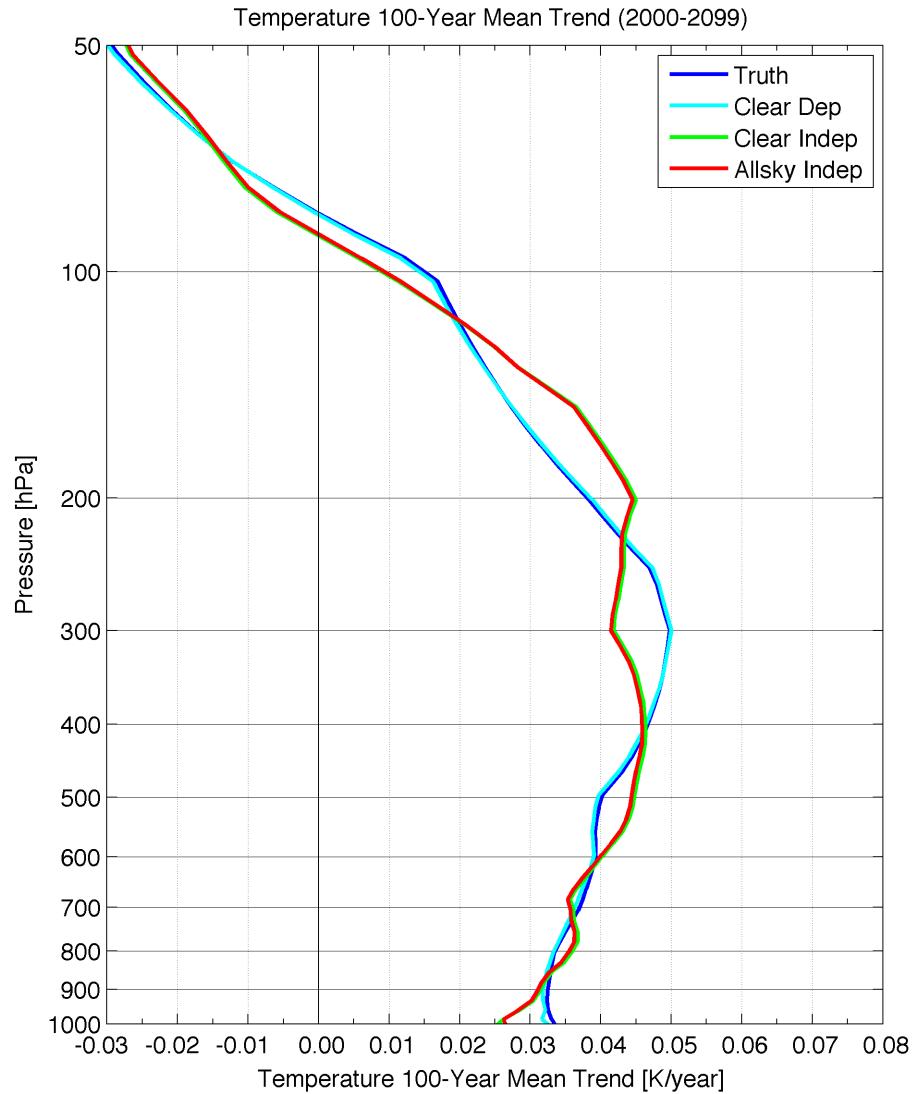


Allsky

Allsky Humidity 100-yr Mean Decadal Tend [(g/kg)/yr] at 850 hPa



100-Yr Global Mean Decadal Trend



Simulating the effects of Multi-level Cloud

- Assume multi-level clouds is a linear combination of a randomly selected cloudy sky pairs from the 18 possible. For every file (18 files per month) and every FOV compute

$$Rcldm_j = (N_j * Rcljd + N_k * Rcldk) / Nm_j$$

where

j ... first cloud level

k ... second cloud level, randomly selected within [j to 18]; note k differs for every FOV and month

N_j, N_k ... scaled (i.e., N/N_{tot}) level cloud fractions

Nm_j ... new cloud fraction with $Nm_j = N_j + N_k$

Rcld, Rmclld ... orginal (single-level), new multi-level cloudy radiance

- Combine 19 retrieved profiles to final profile as before, i.e.,

$$T = (1 - \sum(Nm_j)) * T_0 + \sum(Nm_j * T_j)$$

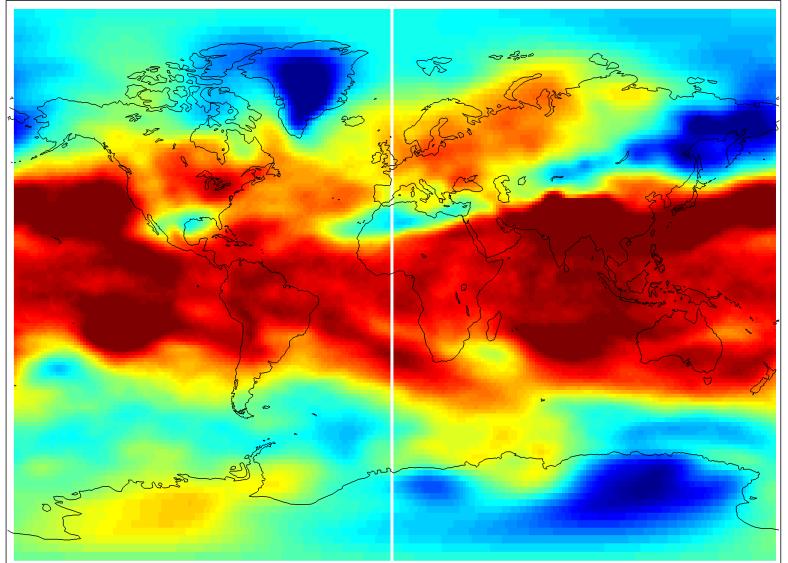
T_0 ...clear retrieval

T_j ... cloudy retrieval, Nm_j ... cloud fraction, with $i=1,2,\dots,18$.

250 hPa 2050-2060 Decadal Trend (K/yr)

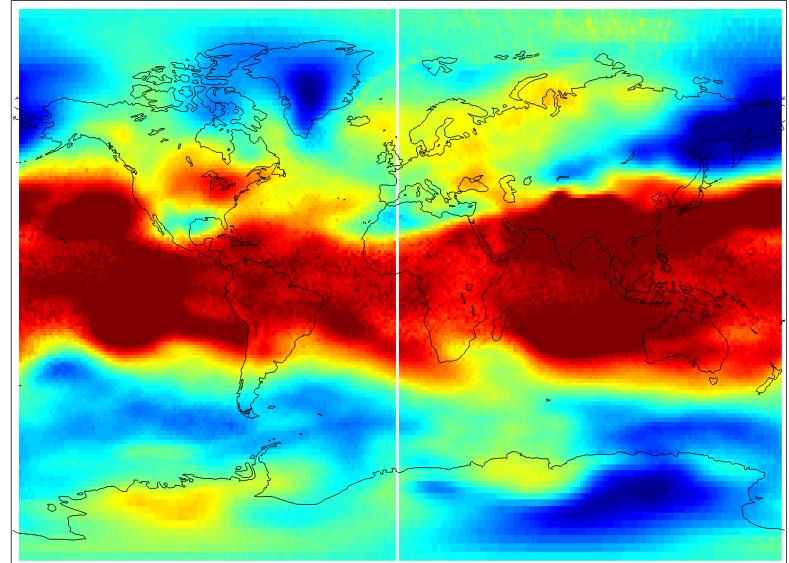
Truth

True Temperature 2050-2059 Decadal Tend [K/yr] at 250 hPa



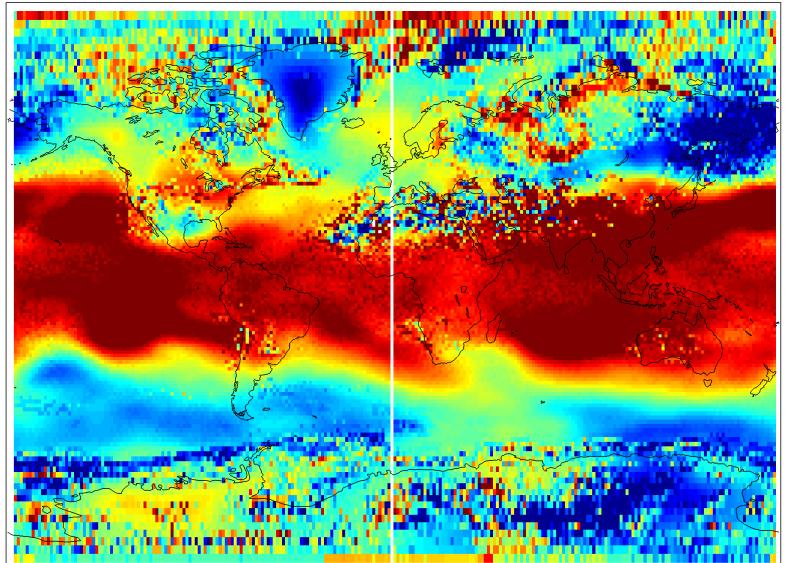
Clear

Clear Indep Temperature 2050-2059 Decadal Tend [K/yr] at 250 hPa



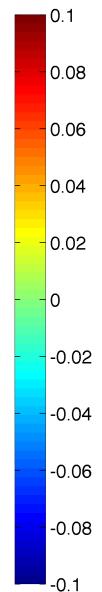
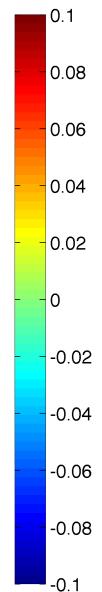
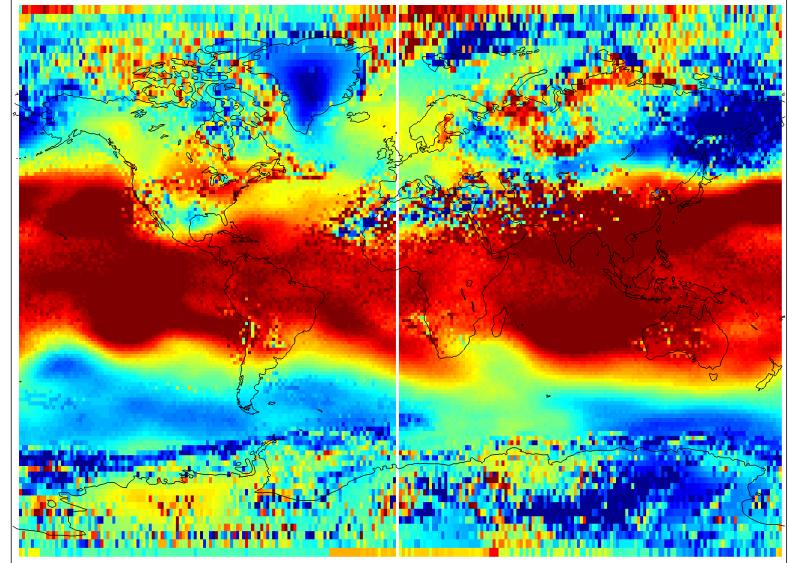
Single Level Cloud

Allsky Indep Temperature 2050-2059 Decadal Tend [K/yr] at 250 hPa



Multi-Level Cloud

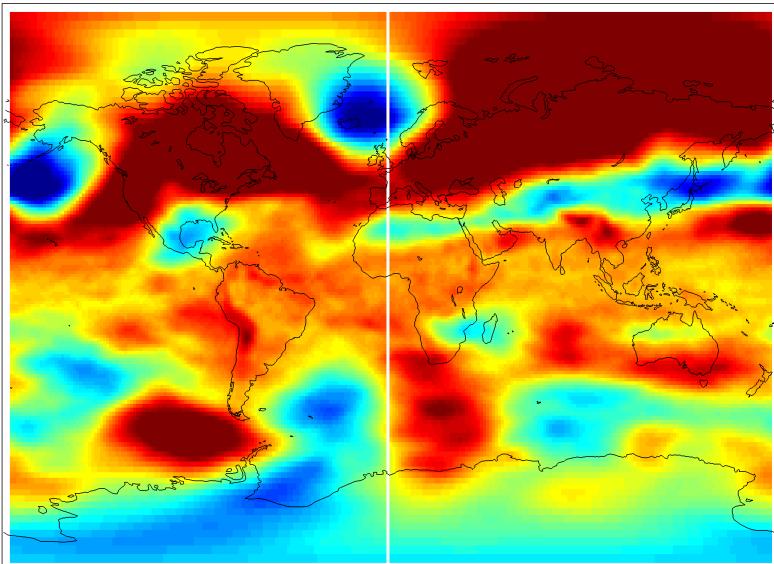
Allsky Indep MLC Temperature 2050-2059 Decadal Tend [K/yr] at 250 hPa



500 hPa 2050-2060 Decadal Trend (K/yr)

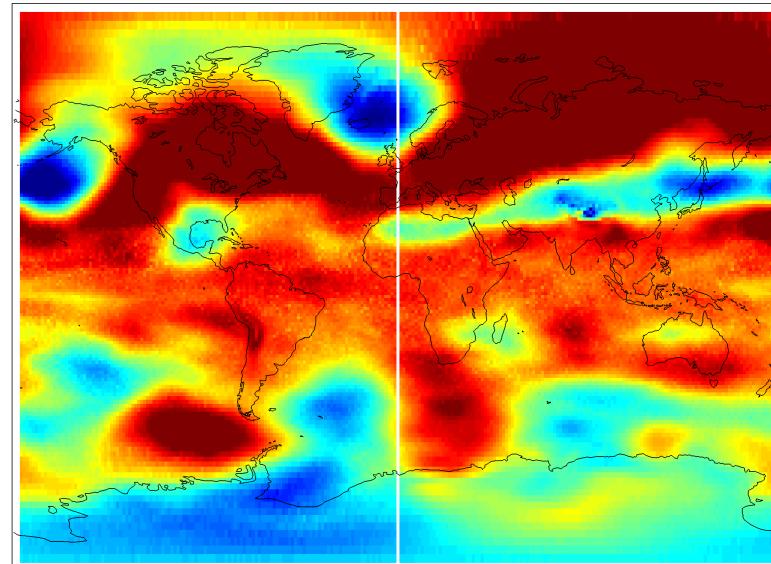
Truth

True Temperature 2050-2059 Decadal Tend [K/yr] at 500 hPa



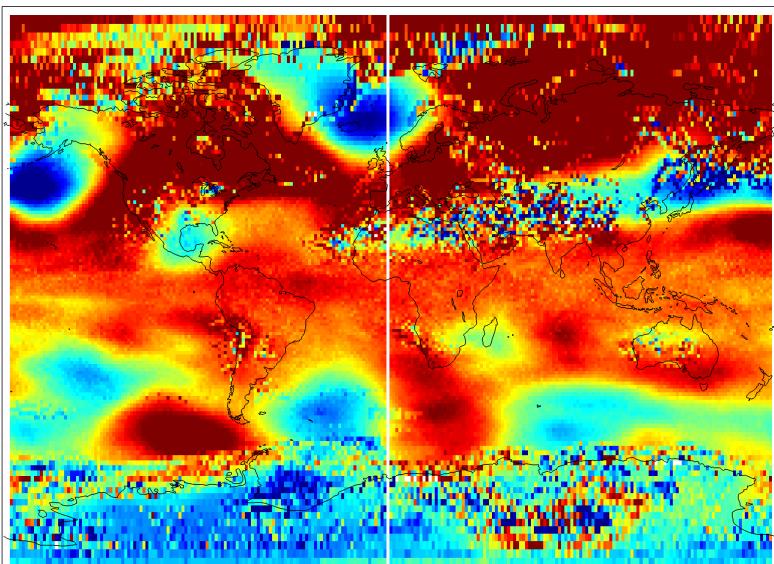
Clear

Clear Indep Temperature 2050-2059 Decadal Tend [K/yr] at 500 hPa



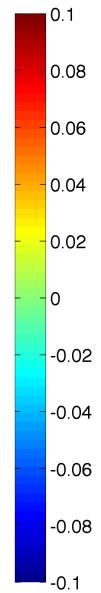
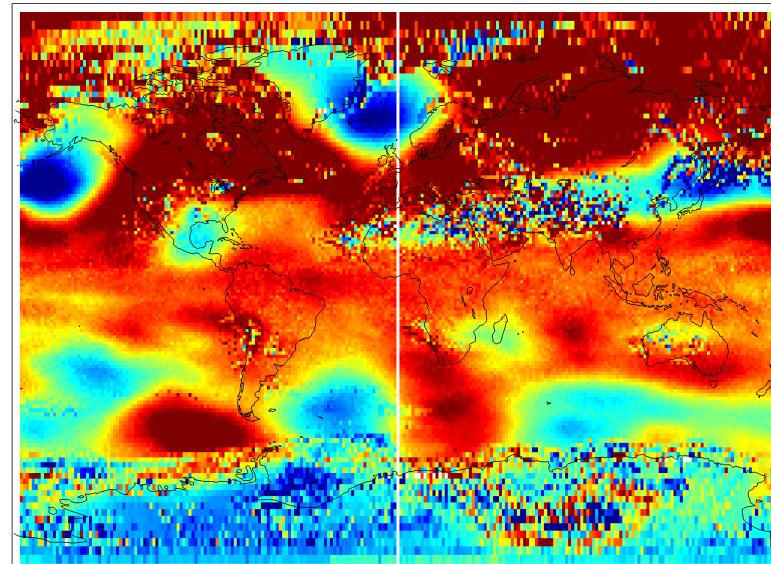
Single Level Cloud

Allsky Indep Temperature 2050-2059 Decadal Tend [K/yr] at 500 hPa



Multi-Level Cloud

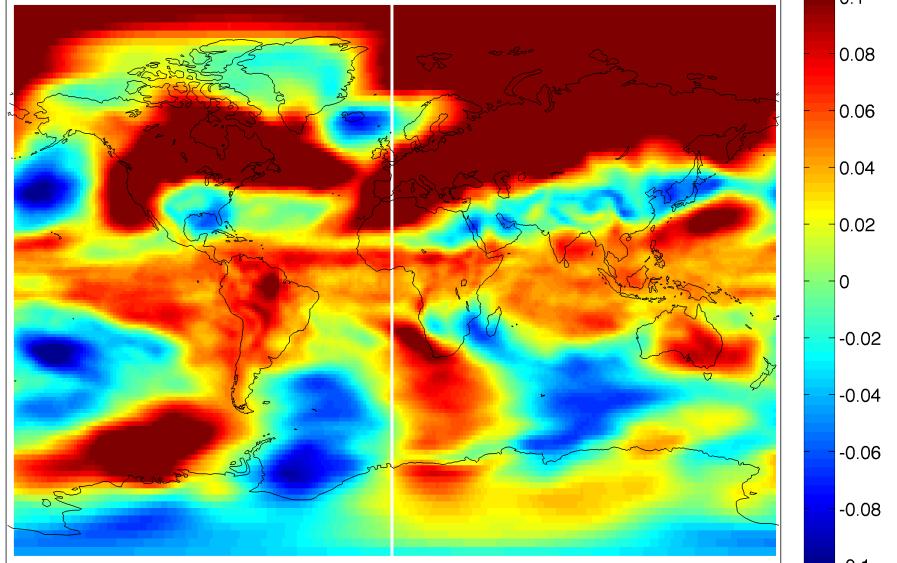
Allsky Indep MLC Temperature 2050-2059 Decadal Tend [K/yr] at 500 hPa



850 hPa 2050-2060 Decadal Trend (K/yr)

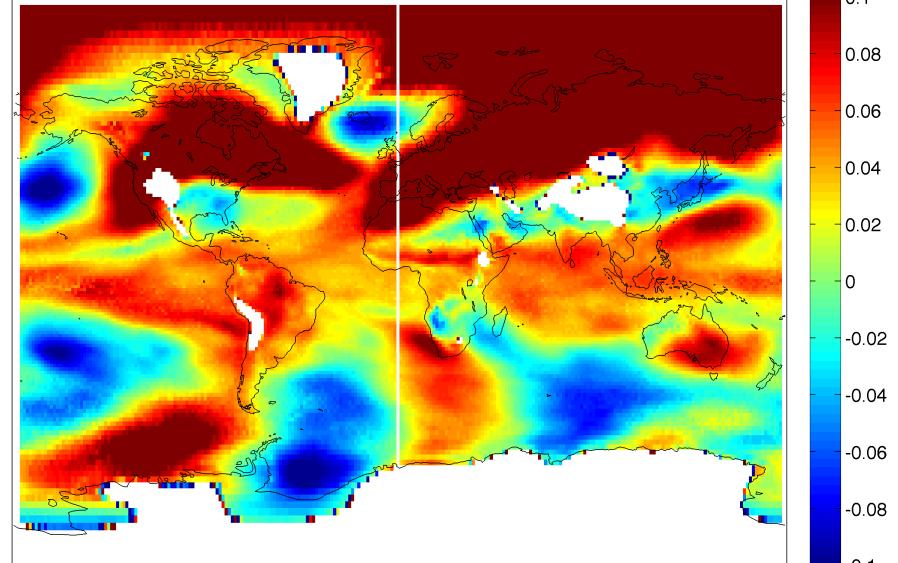
Truth

True Temperature 2050-2059 Decadal Tend [K/yr] at 850 hPa



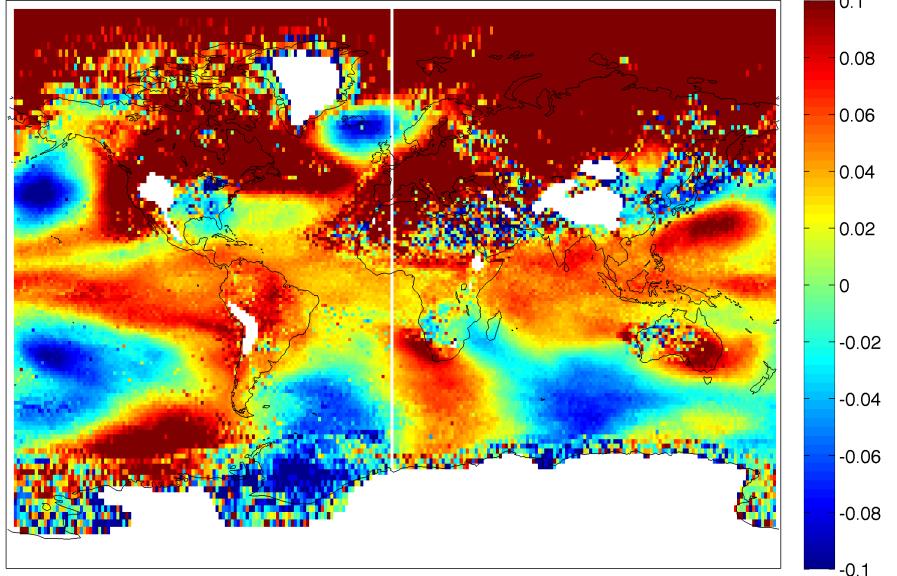
Clear

Clear Indep Temperature 2050-2059 Decadal Tend [K/yr] at 850 hPa



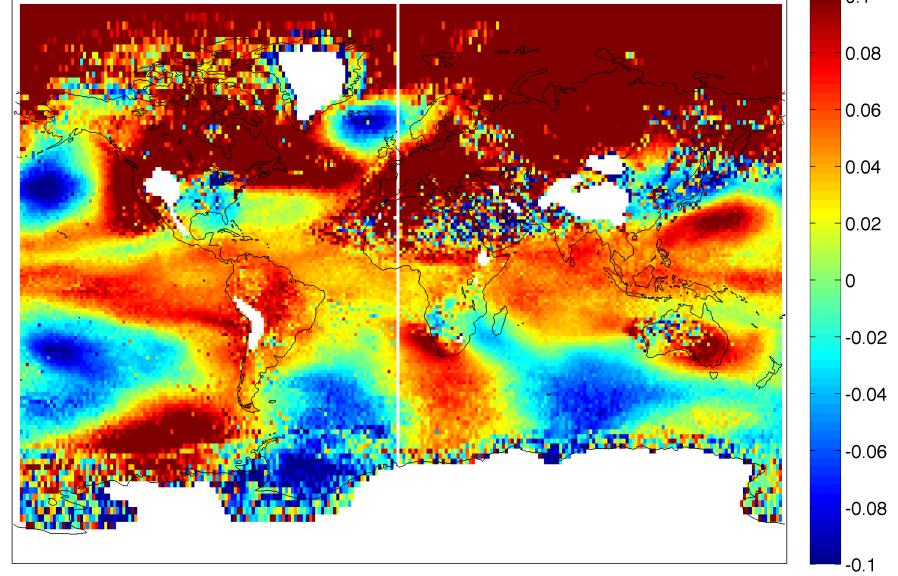
Single Level Cloud

Allsky Indep Temperature 2050-2059 Decadal Tend [K/yr] at 850 hPa



Multi-Level Cloud

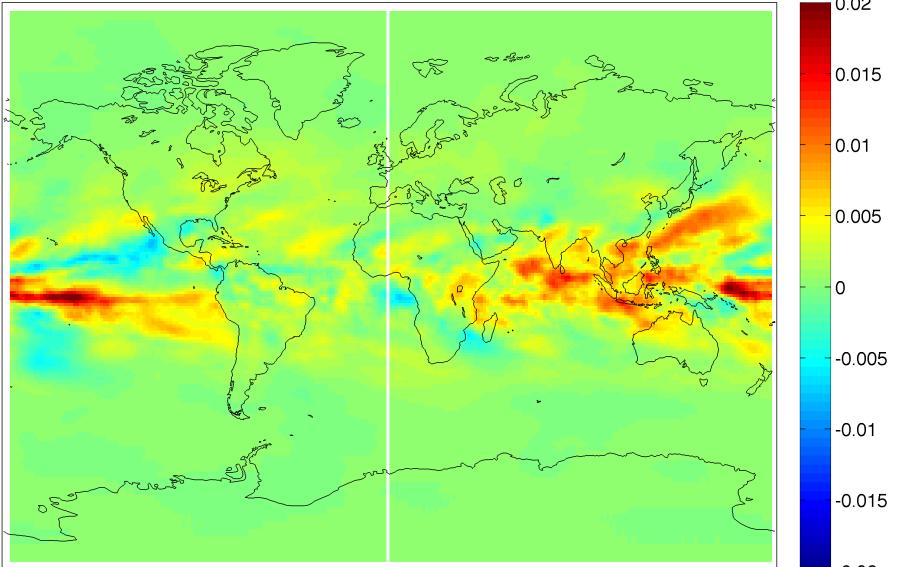
Allsky Indep MLC Temperature 2050-2059 Decadal Tend [K/yr] at 850 hPa



300 hPa 2050-2060 Decadal Trend (g/kg/yr)

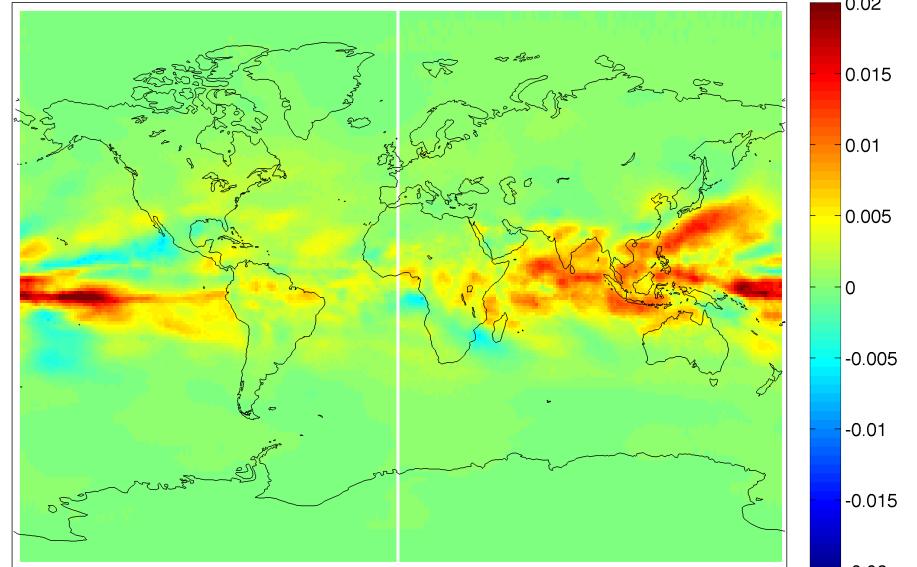
Truth

True Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 300 hPa



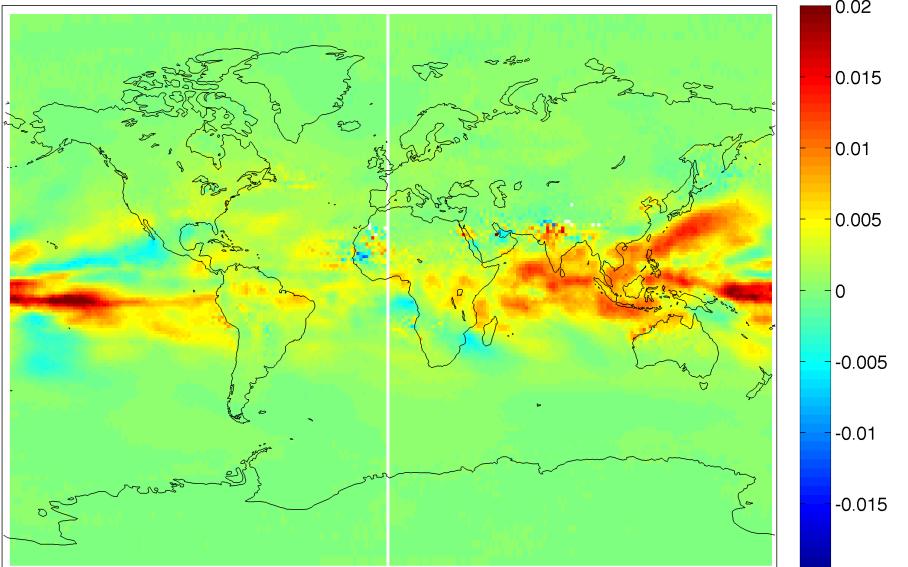
Clear

Clear Indep Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 300 hPa



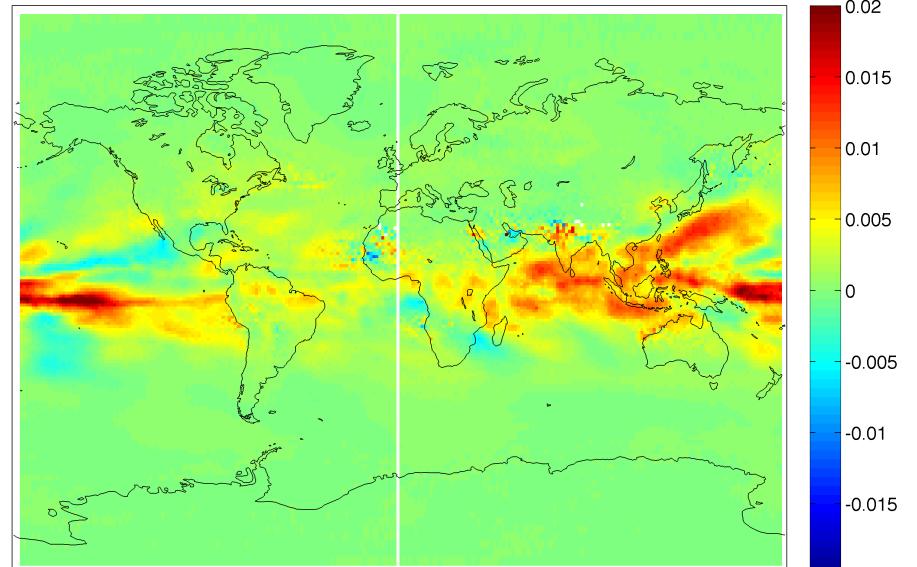
Single Level Cloud

Allsky Indep Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 300 hPa



Multi-Level Cloud

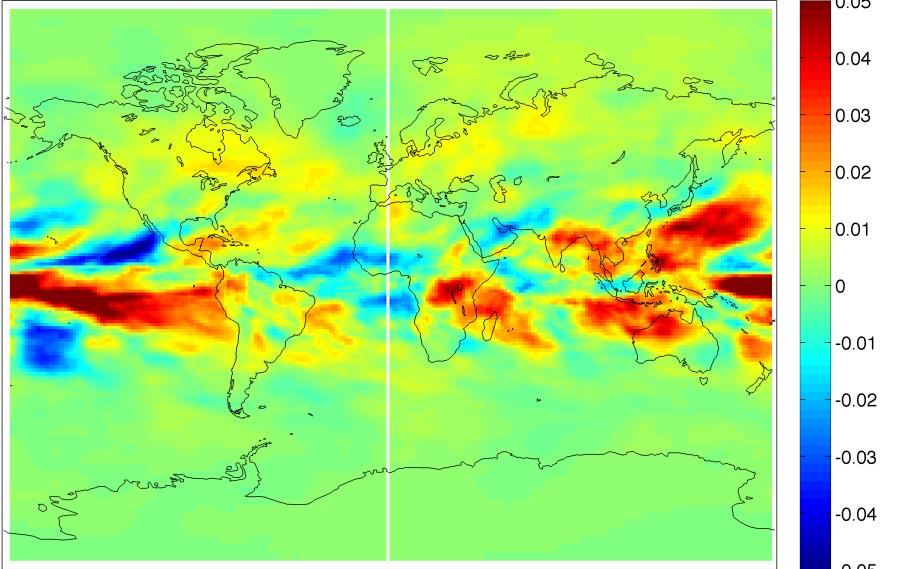
Allsky Indep MLC Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 300 hPa



500 hPa 2050-2060 Decadal Trend (g/kg/yr)

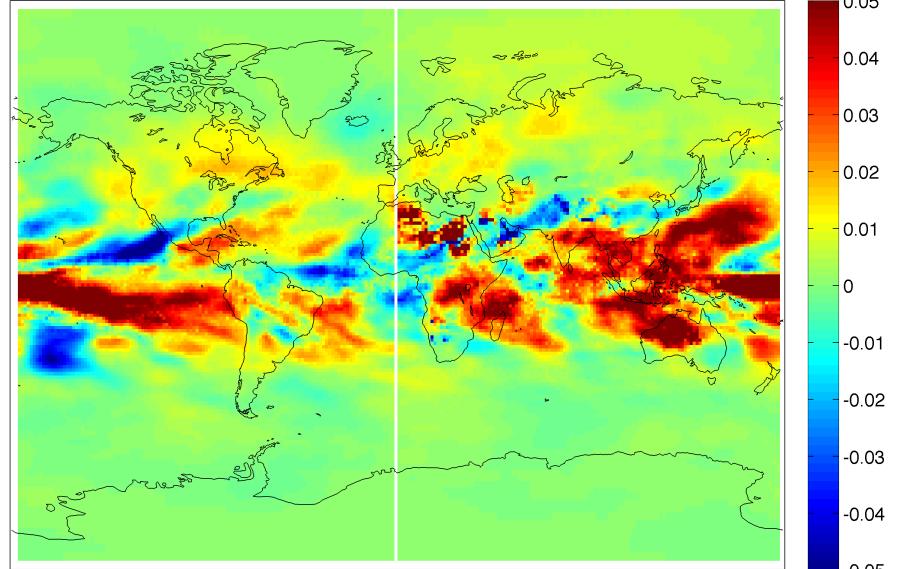
Truth

True Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 500 hPa



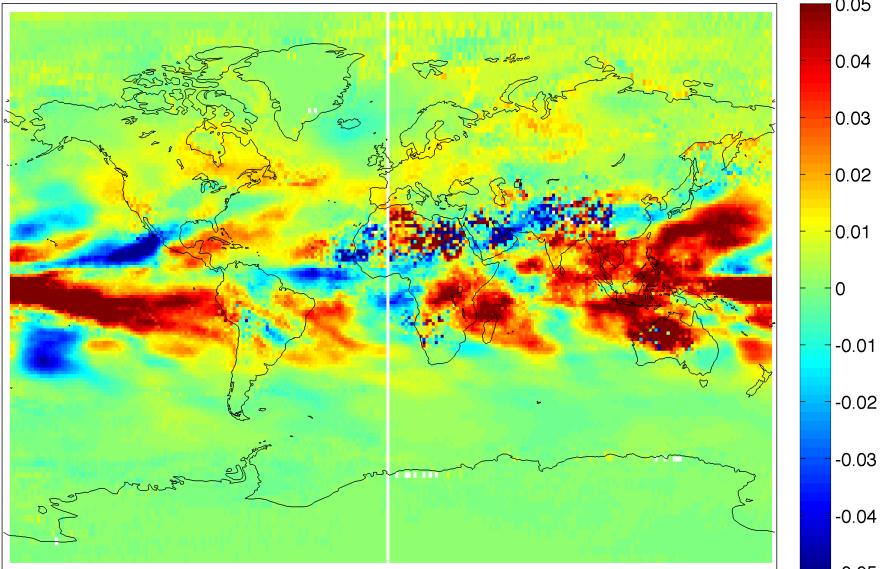
Clear

Clear Indep Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 500 hPa



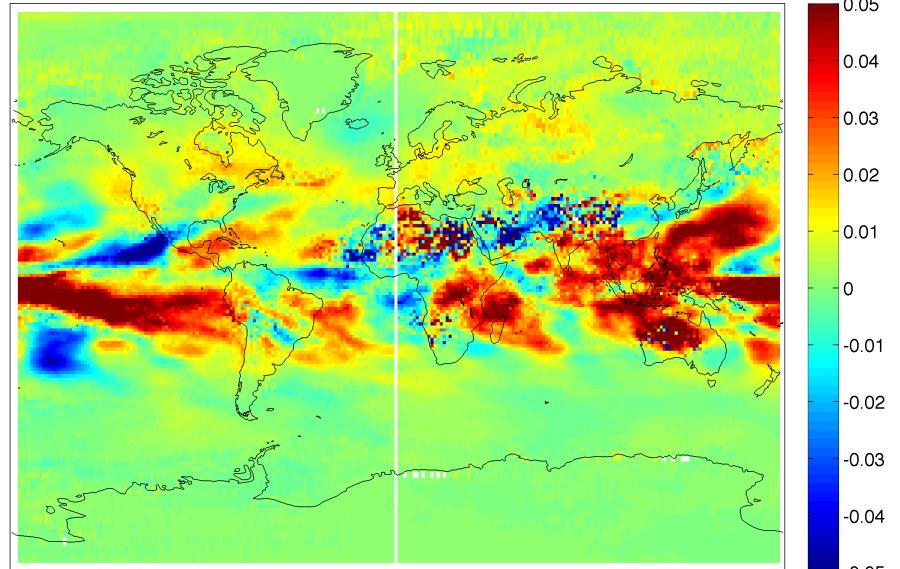
Single Level Cloud

Allsky Indep Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 500 hPa



Multi-Level Cloud

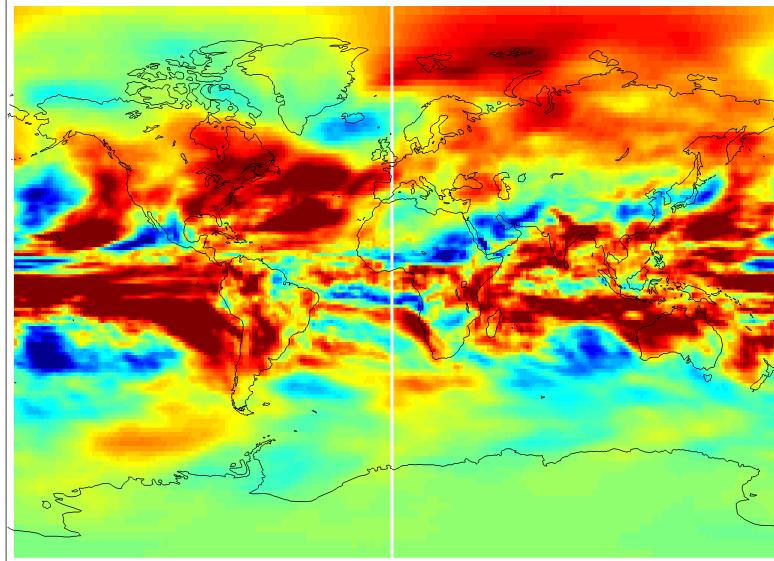
Allsky Indep MLC Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 500 hPa



850 hPa 2050-2060 Decadal Trend (g/kg/yr)

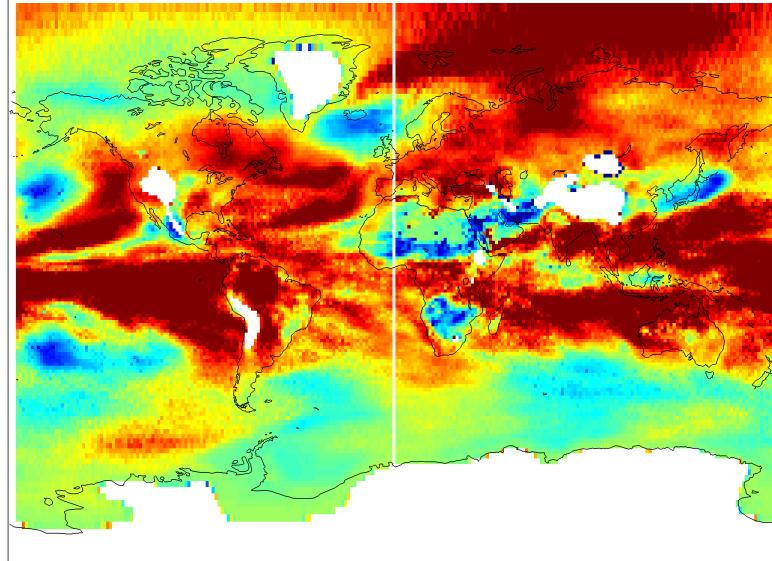
Truth

True Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 850 hPa



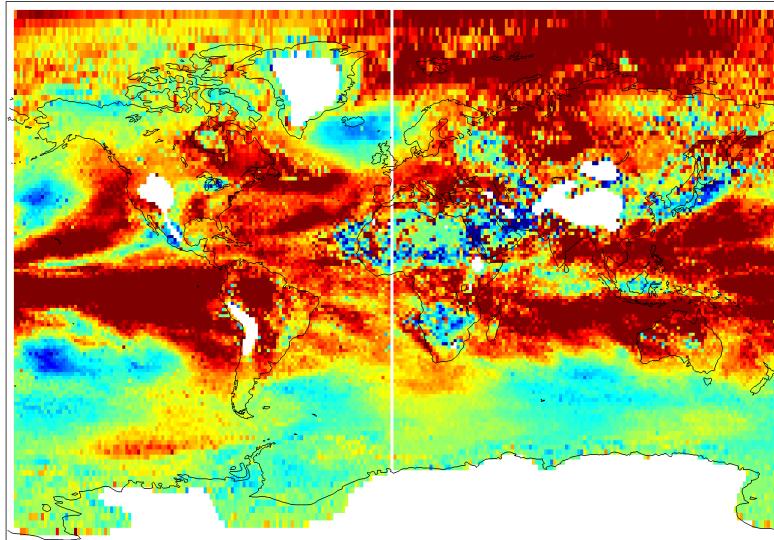
Clear

Clear Indep Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 850 hPa



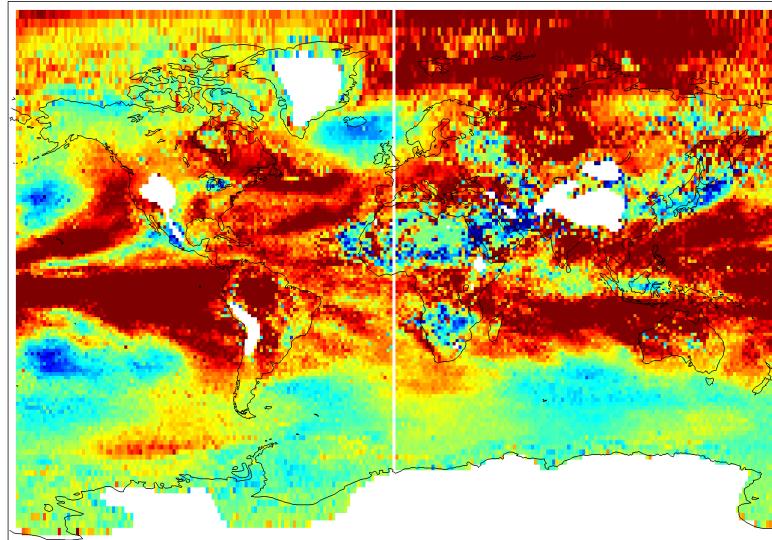
Single Level Cloud

Allsky Indep Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 850 hPa



Multi-Level Cloud

Allsky Indep MLC Humidity 2050-2059 Decadal Tend [(g/kg)/yr] at 850 hPa



Global Decadal (2050-2060) Trend

Temperature [K/yr]

Pressure [hPa]	OSSE Truth	Clear Indep	Allsky Indep	All Indep <u>MLC</u>
50	-0.0259	-0.0253	-0.0249	-0.0250
250	0.0531	0.0472	0.0476	0.0475
500	0.0420	0.0495	0.0500	0.0498
800	0.0384	0.0399	0.0416	0.0416

← ~ 10% Difference →

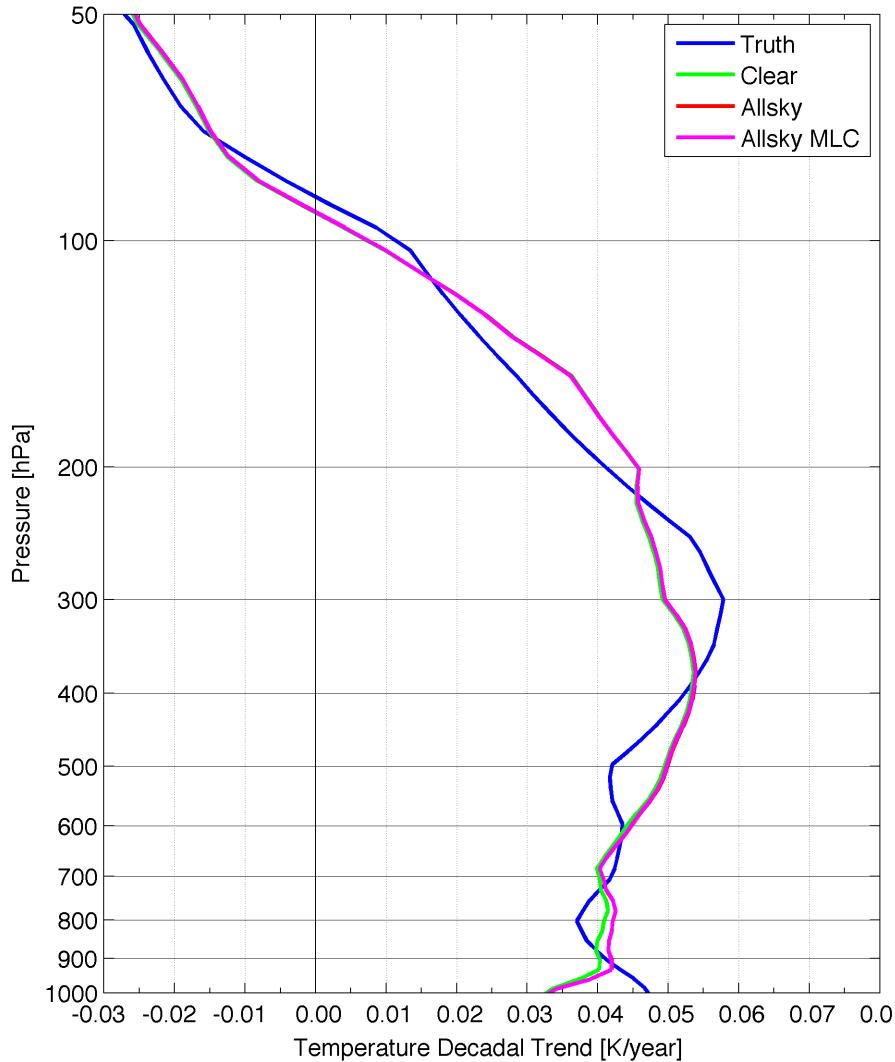
← ~ 1% Difference →

Humidity [g/kg/yr]

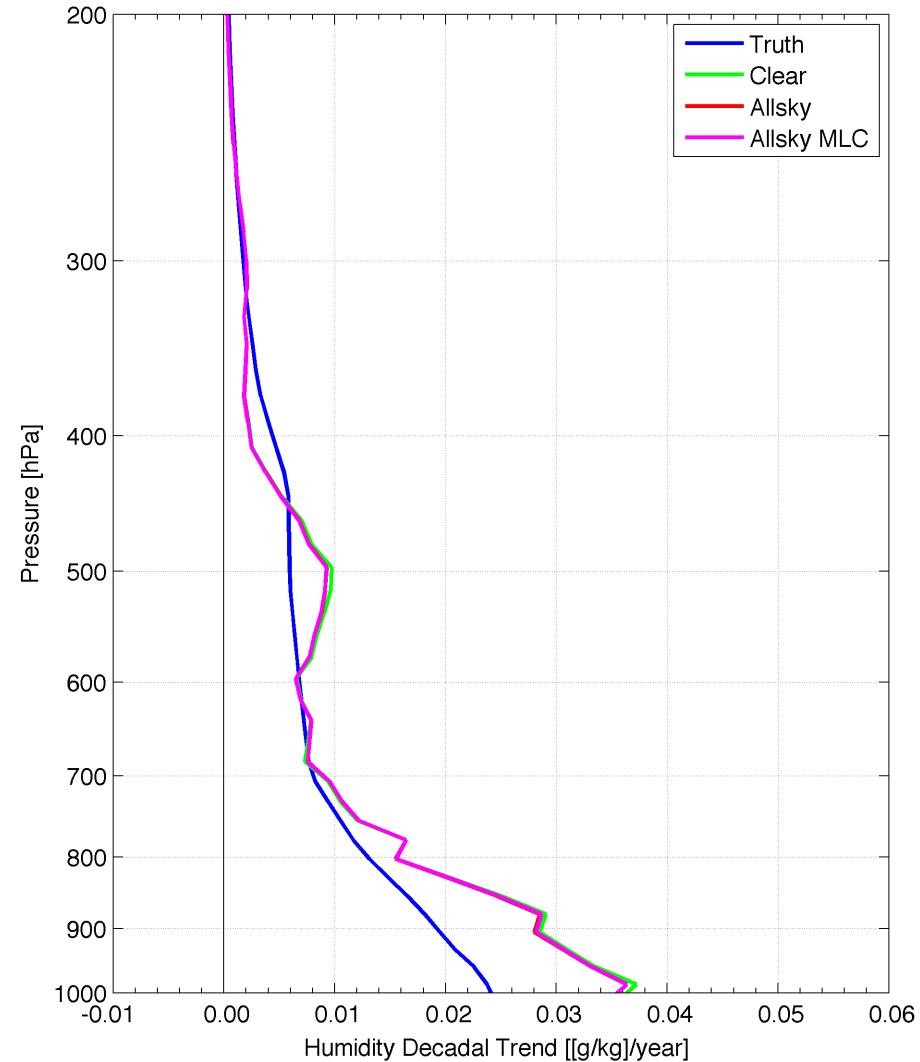
Pressure [hPa]	OSSE Truth	Clear Indep	Allsky Indep	All Indep <u>MLC</u>
300	0.0017	0.0020	0.0020	0.0020
500	0.0059	0.0097	0.0093	0.0092
800	0.0165	0.0250	0.0246	0.0247

Temperature and Humidity Profile Global Decadal (2050-2060) Trend

Temperature Decadal Trend (2050-2059)



Humidity Decadal Trend (2050-2059)



Conclusions

- Linear regression retrievals from clear sky hyperspectral IR radiances can provide accurate decadal trends (i.e., dependent climate model trained clear sky result matches “Truth”)
- Independent contemporary clear sky weather profile training yields results similar (i.e., within 10%) dependent sample results
- For the case where the atmospheric profiles are uncorrelated with cloudiness
 - All-sky results are of similar in accuracy relative to clear sky results (~ 1% difference)
 - Multi-level clouds result in uncertainties similar to those of single level clouds and have little impact on globally averaged decadal trends.

Limitations

- Assumed that the profiles are independent of the cloudiness (i.e., radiances are computed using the same grid point monthly averaged profile for all cloud conditions specified for a given grid point and month)
- Assumed grid point averaged radiance is a linear combination of clear sky and single level cloud radiances (i.e., high spatial resolution hyperspectral instrument). However, prior real data (i.e., AIRS) studies indicate that global trends derived from DR retrievals are relatively independent of instrument FOV size
(i.e., 100 km FOV = 15 km FOV Results)

Next Step

- Compare real IASI data Dual-Regression All-sky retrieved decadal (2007 – 2016) profile trends with the climate model IASI OSSE radiance retrieved profile results for the same period.

Thank You for Your Attention